THE UNIVERSITY OF ALBERTA

# WATER PROBLEMS IN IN-SITU OILSANDS DEVELOPMENT
# THE WATER RESOURCES OF THE GREGOIRE LAKE BASIN

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

FALL, 1976

Abstract

There are many water resources problems associated with development of the oilsands deposits in northern Alberta. It has become evident that these will not be limited to the strip-mining operations presently in operation, but will also be significant factors in the more widespread in-situ recovery processes. Some of these problems are related to water supply and disposal requirements, but the broader land use conflicts involving alteration of the watershed are potentially more serious.

The purpose of this thesis is to investigate the potential dangers in-situ development of oilsands at Amoco's Gregoire Lake Experimental Site might have on the water resources of the Gregoire Lake Basin, and consequently upon the quality of water for recreational and other uses at Gregoire Lake Provincial Park. Other in-situ operations in the Cold Lake and Ft. McMurray areas were also investigated to provide some additional perspective.

Several general and specific water management problems are evident from reviews of both the historical stream flow data and climatic water balance calculations, and the investigations into potential water quality hazards. Problems during the initial phases of development are related to increases in both the total quantity and rapidity of run-off, erosion and sedimentation. Subsequent reclamation may result in some potential for alteration of water chemistry in

Gregoire Lake and increased run-off will continue to be a problem. Estimates of run-off from in-situ sites have been calculated from a mapping of soil moisture storage capacities and climatic water balance calculations using Thornthwaite procedures. Internal plant water budgets have been estimated utilizing data from present experimental process requirements. A theoretical integrated site water balance has been established from this climatic data and process data.

Inspection of other in-situ sites in the province and interviews with the personnel involved indicate some additional environmental hazards and land use conflicts as well as some solutions. Many of these solutions may well prove useful in the Gregoire Lake area, while mutual access to development technology related to reclamation problems could prove advantageous to all concerned.

Acknowledgments

The assistance and cooperation of a number of people was helpful in the completion of this thesis. Foremost among those who deserve my thanks is Professor Arleigh H. Laycock. Dr. Laycock's constructive criticism in all phases of the thesis work was greatly appreciated. Working under him in this and other aspects of my work toward the degree requirements was a rewarding experience.

A number of individuals were helpful in various aspects of the thesis work. I wish to thank Arch Landals of the Alberta Provincial Parks Division (Planning and Design Branch) for the funding that made the study possible, as well as other assistance and advice. Many members of the oil industry were instrumental in my gaining an understanding of production processes in the oilsands; among these are John Nodwell of Imperial Oil, C.E. Anderson of Texaco, and Ron Findlay and Ralph Guiguere of Amoco. Ken Campbell and Cal Bricker of the Alberta Remote Sensing Centre were very helpful both in providing access to remote sensing equipment and in sharing their expertise. In the final stages of the thesis preparation I am indebted to Geoff Lester of the University of Alberta Geography Department for his advice in the preparation of the maps and figures, and to my excellent typist, Peggy Schmidt.

It is not possible to thank all those who were helpful, in ways both great and small. Among those I would like to single out are

Mr. and Mrs. Bill Cary of Ft. McMurray, and their daughter, Pat, for their numerous kindnesses during my field work. Finally, I wish to express my gratitude to Scott and Brenda Witter. Scott's advice in the remote sensing aspects of the thesis was extremely helpful. The Witter's friendship and support throughout the thesis program cannot be overestimated.

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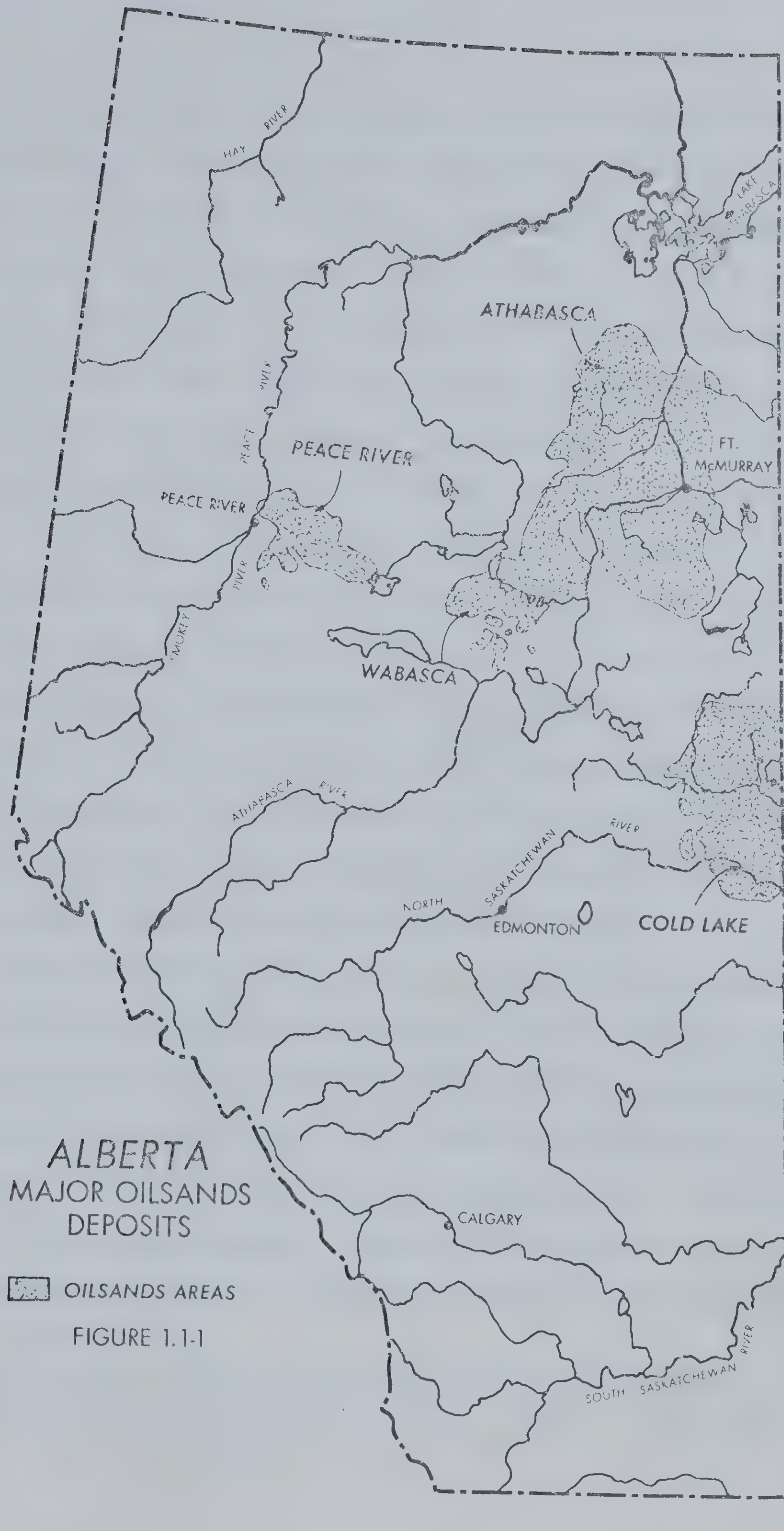
# Chapter I

# Introduction

## 1.1 Definition of the Problem:

The Alberta Oilsands, constituting in-place reserves of approximately 895 billion barrels, have recently come under closer scrutiny as a source of petroleum. The pioneering efforts at the Creat Canadian Oil Sands plant north of Ft. McMurray have proven the commercial feasibility of mining and processing of the oilsands. During the past several years the massive Syncrude strip-mining project has proceeded with construction. More recent activity has been focused upon the development of in-situ reserves. Public concern over the environmental consequences of strip-mining and production process effluent has been apparent since the initiation of developments north of Ft. McMurray. However, the vast majority of the Athabasca deposits will not be developed utilizing surface mining techniques, but will be exploited using in-situ extraction technology (Alberta Mines and Minerals, 1974). When the Cold Lake, Wabasca and Peace River oilsands deposits are included, it becomes evident that only about four per cent of the Alberta Oilsands may be subject to the disruptions involved with strip mining. At present, no commercial in-situ developments are past the planning stages. In spite of this, the activities at several of the pilot plants make it evident that in-situ development also may have a substantial impact upon the environment when enlarged to a commercial scale. Due to the volumes of water involved in the production processes and the clearing of vegetation over large areas, the in-situ development sequence will have a particularly significant effect upon watershed capability in terms of water yield, regime and quality (Figure 1.1-1).




ALBERTA
MAJOR OILSANDS
DEPOSITS

OILSANDS AREAS

FIGURE 1.1-1

One of the earliest in-situ pilot plants is located south of Ft. McMurray near Gregoire Lake (see Figure 1.1-2). Some concern has recently been expressed over possible dangers this plant might pose to the watershed of the Gregoire Lake drainage basin and to Gregoire Lake Provincial Park.[1] The work at the Gregoire Lake Experimental site is being conducted by Amoco in the area drained by Surmont Creek, a major tributary of Gregoire Lake. The development sequence involves the clearing of many well sites (each approximately one acre or 0.4 hectares in area) and service roads, eventually resulting in clearance of up to ninety per cent of the forest cover in the production area. Much of the lease area, including the pilot plant site, is in an area of high erosion potential. Amoco has been reasonably conscientous in their attempts to avoid degradation of the environment through various protective and corrective measures. These measures have certainly reduced erosion at the site, with the consequent lessening of water quality problems (eg. sedimentation) that might have occurred had these measures not been taken.

Much of the work done in the area calls for earth moving to be done in the winter months when surfaces are frozen; the tractability of surfaces in summer is low owing to high soil moisture content and in some cases, muskeg conditions. It is impossible to fully protect these areas against erosion using present techniques during the first spring run-off period after clearing. Spring run-off from those areas cleared during the preceding winter's operations may then find its way into

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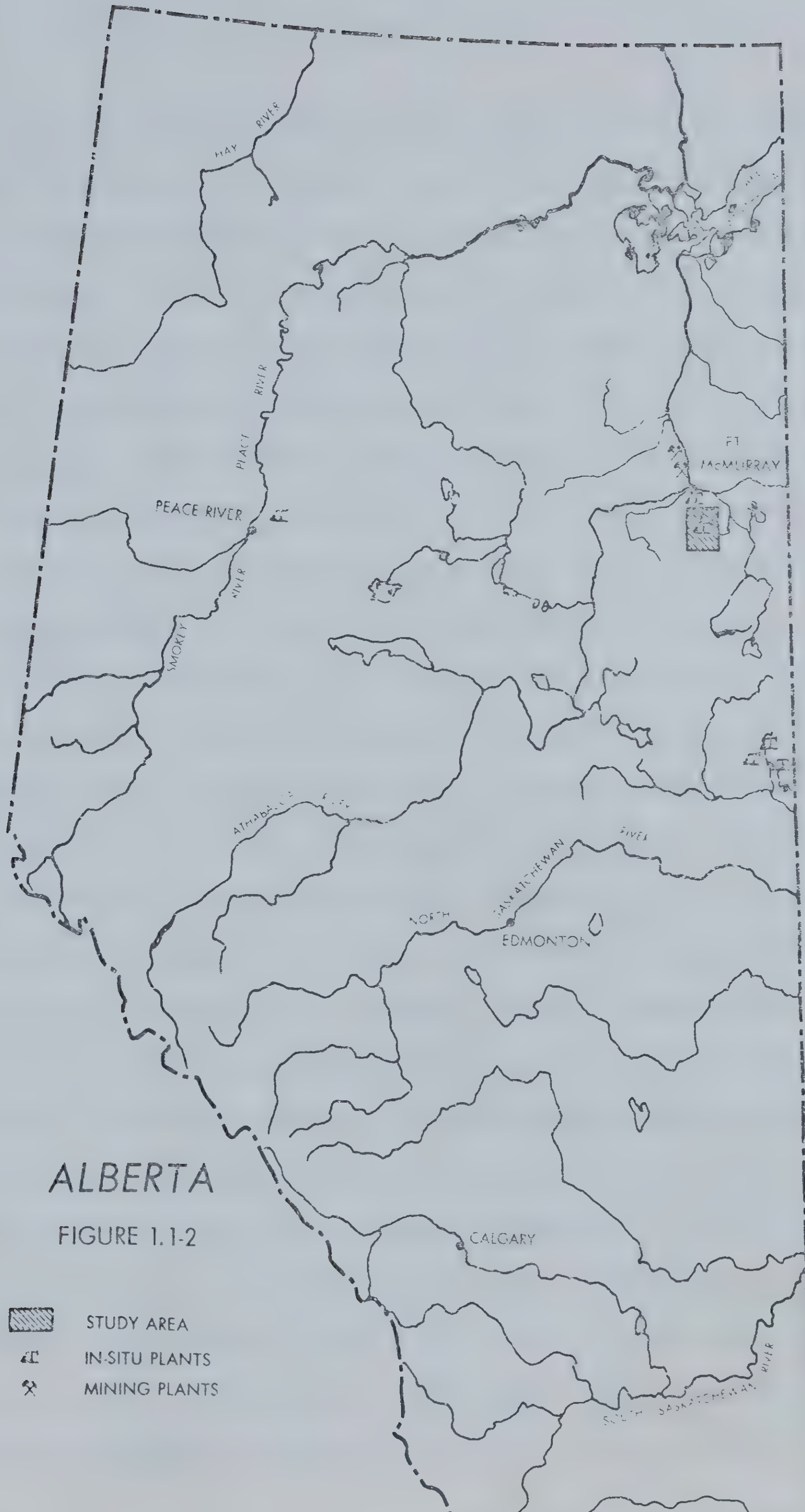
[1]Archie Landals (Alberta Parks, Recreation and Wild Life) has suggested the potential for damage to Gregoire Lake. Concern over clearing practices and erosion was expressed by Oliver Glanfield (Alberta Forestry Service)(1975).




ALBERTA

FIGURE 1.1-2

STUDY AREA
IN-SITU PLANTS
MINING PLANTS

Gregoire Lake via Surmont Creek, with resulting water quality problems. Due to the existence of a provincial park in the area, officials of the Long Range Parks Planning Branch have expressed concern over the situation. The situation at Gregoire Lake is particularly critical owing to the fact that it is the only available outdoor recreation site offering a wide range of water-based activities within a reasonable driving distance of the rapidly growing settlement of Ft. McMurray. Present plans for extensive expansion of the park facilities are of course contingent upon the maintainence of water quality standards in Gregoire Lake which are compatible with water based recreation.

In-situ development is not limited to the site south of Gregoire Lake. Several miles north of Gregoire Lake (and outside the Gregoire Lake drainage basin) a pilot in-situ plant has been established by Texex (Texaco Oil Co.). Other in-situ experimental plants have been operated for several years near Cold Lake, Alberta, by Imperial Oil Co. New plants are anticipated in that area as a result of present programs of Gulf, Canadian Industrial Gas and Oil, and other companies (See Figure 1.1-2). Gregoire Lake Provincial Park is the only park presently threatened by in-situ development, but several proposed park areas on the west shore of Cold Lake and possibly to the west of it may be affected by proposed or potential in-situ development. The immediate problem exists, then, in the Gregoire Lake Area. However, it is clear that resource use conflicts in the future will not be limited to this area, but may occur wherever in-situ development takes place within the province of Alberta. Further, it is likely that one of the

major resource categories involved in these conflicts will be Alberta's water resources.

## 1.2 Proposal:

It was proposed that a study of the water resources of the Gregoire Lake drainage basin be conducted to determine the steps necessary for protection of the lake and consequently Gregoire Lake Provincial Park from the possible hazards associated with in-situ development (Figure 1.2-1). This involved establishment of baseline conditions relating to the water resources of the area, determination of existing and potential effects of in-situ development, and the outlining of possible protective measures. The existence of in-situ pilot plants outside the Gregoire Lake area provided an opportunity to observe some development and reclamation techniques other than those in use at the Gregoire Lake site and to make some evaluation of the potential of these techniques. Finally, some general recommendations relating to the development and reclamation programs of in-situ oilsands production and their impacts upon watershed quality were possible.

The study undertaken included the following steps, with field work carried out during the 1975 season:

1. Analysis of the general hydrology of the study area, with special emphasis on Surmont Creek and Gregoire Lake.
2. Determination of the water balance patterns of the study area, with emphasis upon the effects of relatively wet years.

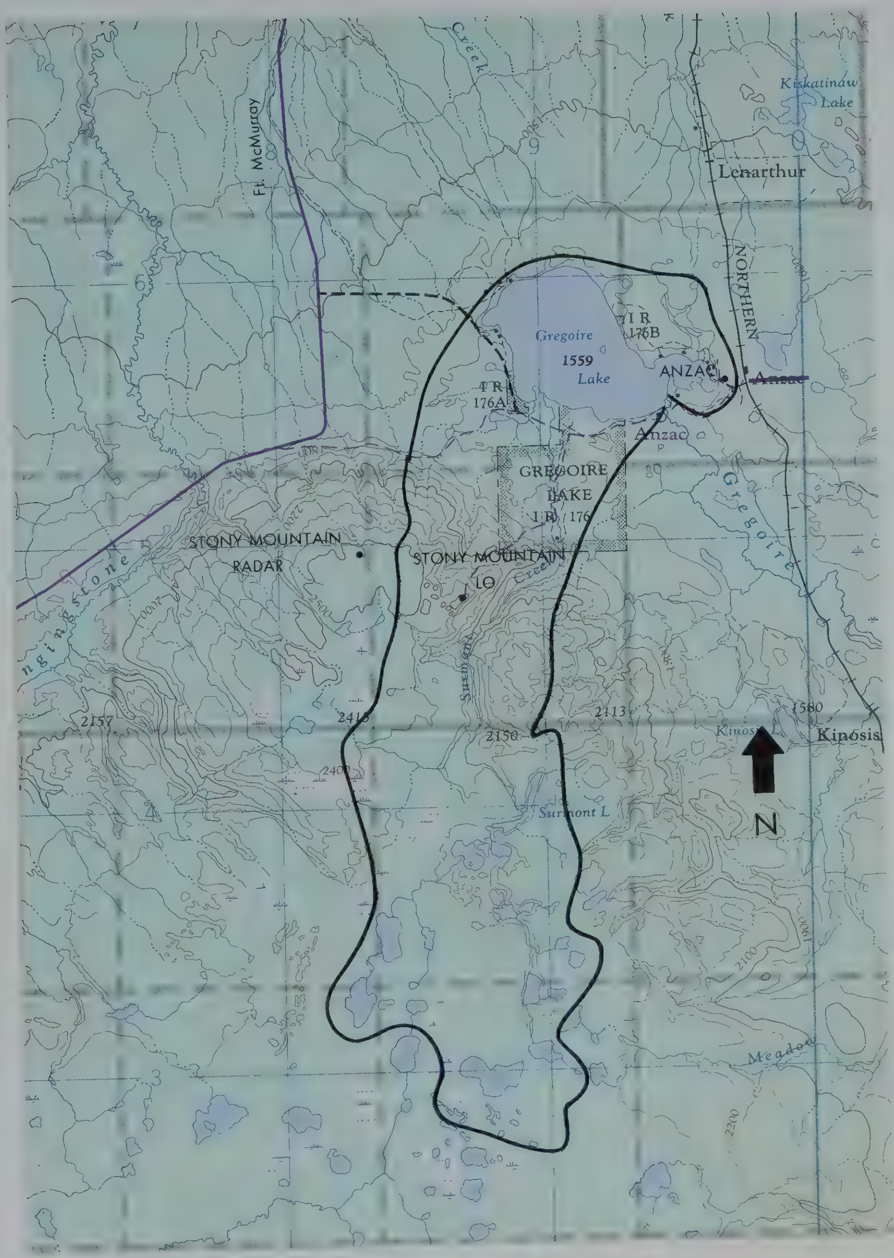



Figure 1.2-1: The Gregoire Lake Area. (1:250,000)

Ft. McMurray
ANZAC
STONY MOUNTAIN
RADAR
STONY MOUNTAIN
LO
N

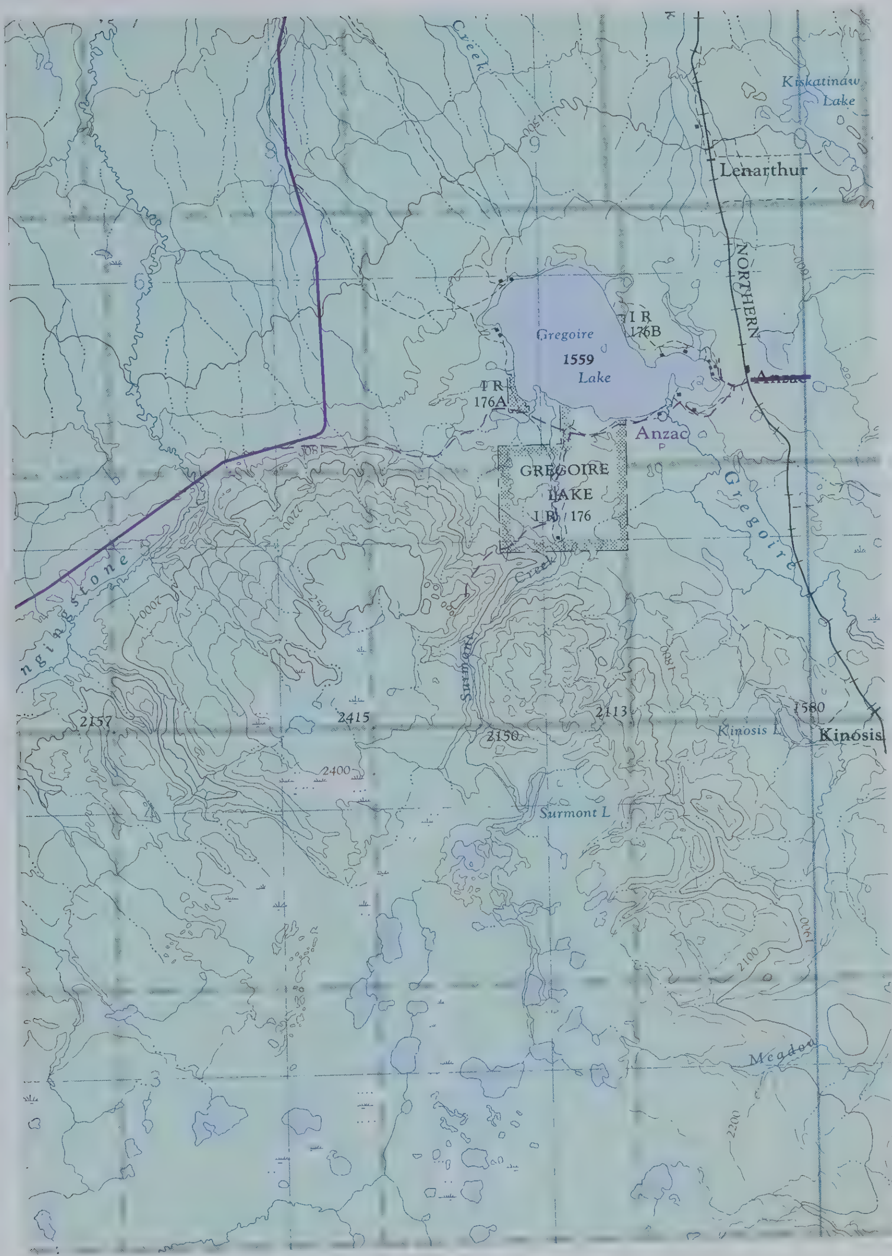



Figure 1.2-1: The Gregoire Lake Area. (1:250,000)

3. Determination (as nearly as possible) of the "natural" water quality of the area as it relates to the present and potential uses. Included here is the natural variation of water quality over time.
4. Determination of the potential water management problems in the Surmont Creek-Gregoire Lake basin (especially the patterns of wet and dry years with their consequent flooding and drought problems), with reference to the general hydrologic characteristics and the water balance patterns. Short term flow fluctuation was also investigated, with an emphasis being placed on rapid run-off characteristics.
5. Determination of the effect of the Amoco Gregoire Lake Experimental Site development upon the water quality of the study area; some projections related to Amoco's future development plans were also included.
6. Evaluation of the relationship between natural water quality and the effects of in-situ development upon that quality, with emphasis on the Surmont Creek-Gregoire Lake Basin.
7. Conduct reconnaissance surveys of present in-situ work at the Texex site near the Ft. McMurray airport and the Imperial site near Leming Lake and note the potential effects of those developments on the respective water resources of their areas.
8. Suggestions of possible solutions to present and future water resources use problems, with emphasis upon

those of the Gregoire Lake area.

## 1.3 Procedures:

The general hydrology of the area has been reviewed through the analysis of stream hydrographs based upon measurements within and near the study area. Most relevant to the studies in the Gregoire Lake area are those based on data for the Hangingstone River gauge, in operation since 1965, and the Gregoire Lake stage gauge, in operation since 1969. The Hangingstone River is not within the Gregoire Lake drainage basin, but it drains an area with very similar characteristics adjoining that portion of the Stony Mountain Plateau drained by Surmont Creek. Owing to this, the Hangingstone River hydrographs may be valuable indicators of conditions in the Gregoire Lake Basin during years other than the study season. Other gauges in the region do not record flow characteristics similar to those of the study area, but some may be used as additional indicators of expected natural hydrologic conditions within the study area. The hydrogeology (Ozoray, 1974) and surficial geology (Bayrock and Reimchen, 1975) of the area are well documented by regional standards. This information is used in the groundwater aspects of the investigation. Interpretation of aerial photography of the vegetative cover patterns in the study area is used to indicate soil moisture storage potential.

The water balance patterns in the area are useful in forecasting the hydrologic conditions. Different storage levels determined from the

above-mentioned photographic interpretation, and soil moisture storage tables calculated using the Thornthwaite method, are utilized in these predictions. Meteorological data from the Ft. McMurray Airport stations and summer records from the Stony Mountain Fire Tower (Stony Mountain LO) will be used. In addition, some year-long data are available from the Anzac station, located in the hamlet of Anzac, and from the Stony Mountain site located just outside the study area at the now abandoned radar site (see map 1.2-1). While long term records are not available for these stations, the records are of long enough duration that some water balance calculation has been possible. The Stony Mountain LO station, by virtue of its location near the edge of the Stony Mountain Escarpment, is a good indicator of orographically induced precipitation caused by uplift over Stony Mountain. This station is also ideally located for monitoring temperature in the upland area during the spring snowmelt period.

Snowmelt is often an important factor in recharing soil moisture storage prior to and during the spring run-off period. Soil moisture storage in many years is fully recharged without snowmelt, in which case the meltwater from entire snowpack is available as surplus. The latter was true of the study area during the winter of 1974-75, but very light snow-fall precluded more than light snowmelt run-off. Some snow sampling was carried out on the escarpment prior to the snowmelt period during the study year. The anticipated monitoring of the snowmelt period in the less accessible portions of the study area utilizing Landsat imagery proved to be impossible due to the cloud

cover during some passes and technical problems at the Canadian Centre for Remote Sensing (CCRS) during others. Imagery of Canada processed in the United States through the EROS centre is not readily available. In spite of this, imagery from previous years was indicative of the late season snow-pack conditions. Analysis of earlier years' imagery is included as evidence of the general patterns. In future years the rapid processing and ready availability of this information may be useful in predicting stream discharge patterns.

Water quality sampling of Gregoire Creek concurrent with quality sampling of Surmont Creek and an un-named tributary (called Culvert Creek for study purposes), was undertaken periodically throughout the study season in conjunction with stream gauging. A quantitative analysis of the suspended sediment load and a qualitative analysis of the nutrients, solutes and biologically related substances has been undertaken using the services of the University of Alberta Department of Zoology laboratories directed by Don Gallup. Initial testing covered a broad spectrum, but further thorough monitoring of water quality appeared to be unlikely to provide enough additional significant data to justify the expense. However, monitoring of suspended sediment and total solutes was continued throughout the study season. The effect of the present in-situ development on water quality was not evident in the sample analysis, probably owing to the small size of the Amoco development. As a result of the inconclusive nature of the water sample analysis, it was necessary to depend heavily upon on-site inspection of potential hazards at the Gregoire Lake site and

upon interviews with Amoco personnel in defining more closely the development procedures and process requirements.

# Chapter II

## The Physical Setting

## 2.1 Physiography:

The study area can be divided into three broad physiographic areas. Northernmost of these is the basin of Gregoire Lake and the surrounding low plain. The southernmost portion of the area is constituted by the Stony Mountain upland. (This is alternatively spelled "Stoney" Mountain, and is often referred to as "Surmont Mountain". However, the "Stony Mountain" appellation will be used throughout.) Dividing these two areas is the north-facing escarpment of Stony Mountain. This is an area of relatively high relief, the only such feature of note within the study area (refer to Figure 1.2-1).

The plain surrounding Gregoire Lake is an area of very low relief. Elevation within the plain does not have a local variance in excess of seventy-five feet, with many of the lower areas being in muskeg, sloughs and small lakes. About thirty per cent of the total surface area is in lakes and relatively permanent sloughs. Small areas of greater local relief include steep slopes dropping to the water's edge on the northeast shore of Gregoire Lake. What appear to be raised beaches also exist in several locations near the present shoreline.

The escarpment which constitutes the northern flank of Stony Mountain rises above the plain surrounging Gregoire Lake from about 900 feet (275 metres), to an elevation slightly in excess of 2,500 feet (760 metres). Slopes on the escarpment are relatively steep, sometimes in excess of twenty per cent (Amoco, 1974). The face of the escarpment

is relatively well dissected, the main erosional feature being the valley cut by Surmont Creek. Numerous small watercourses tributary to Surmont Creek and Culvert Creek are also incised into the landscape.

The Stony Mountain Plateau is a gently undulating surface at and average elevation of 2,400 feet (730 metres). Local relief generally does not exceed thirty feet (ten metres); however, the northern edge of the escarpment is elevated 100 to 150 feet (30 to 45 metres) above the southern portion of the plateau. This slightly elevated northern rim is breached by Surmont Creek. Numerous small lake basins, in many cases associated with muskeg areas, are located in the southern (lower) portion of the plateau. Few of these lakes exceed one-half of one square mile (roughly one square kilometre) in area.

## 2.2 Climate:

The most marked influences upon the climate of the Gregoire Lake area are its northerly latitude ($56^{o}$ to $57^{o}$) and its continentality. The area is classified as being in the "short, cool summer" or Dfc zone of the Koeppen-Geiger climatic classification (Longley, 1968). This zone is defined as having sufficient warmth in some months to support growth of high-trunked trees (Strahler, 1969). The area is generally snowbound from November through March.

Mean monthly temperatures recorded since 1949 in the area range from a low of -6.3$^{o}$F (-21.3$^{o}$C) in January to a high of 61.3$^{o}$F (16.4$^{o}$C) in July; the mean annual temperature is 31$^{o}$F (-0.6$^{o}$C) (Environment Canada, 1975). The area is generally frost free for approximately 80 to

100 days each year, becoming frost free during the first two weeks in June. The first fall frost is likely to occur during the first two weeks in September. The above frost dates, however, are long term averages; they can vary significantly from year to year.

Long term water balance patterns can be established from weather stations immediately adjacent to the study area. In this study, the records from the Ft. McMurray Airport station were used. Some less complete data from within the study area do exist. Complete year-round records were kept for the Anzac station during the years 1951-56, and also from 1974 through the present. The Stony Mountain Fire Tower personnel also keep records during the fire season, which extends from April or May through September, depending upon the fire danger during any particular year.

Average precipitation at Ft. McMurray is 17.23 inches (438 millimetres). This is quite probably exceeded in the upland portions of the study area (see Chapter IV). Evapotranspiration exceeds precipation by about two inches in an average year, the long term average at Ft. McMurray being 19.20 inches (488 millimetres)(calculations based on the Thornthwaite procedures, 1955, 1957). In average and comparatively dry years there is little surface run-off, since most of the precipitation is used in current evapotranspiration or is stored in forest and muskeg soils for later evaporation and transpiration. Even a relatively wet year may not be reflected by a proportionally great stream discharge if soil moisture storage capacities are not greatly exceeded. As is the case with the prairies further to the south, a maximum of

precipitation is in the summer months. As was the case with the 1975 study year, stream run-off maxima are often associated with rain storm sequences rather than with snowmelt. In such years the recharging of soil moisture storage with snowmelt waters sets the stage for later surpluses. However, peak flow in most other years results from snowmelt because summer precipitation is largely balanced by evapotranspiration. The hydrological significance of these water balance patterns is readily apparent, and is more fully discussed in Chapter IV. During the winter months the climate is governed by the presence of the relatively cold, dry Polar continental air mass. Several air masses are present during the summer months. Most of these have their origin over the Pacific Ocean; cyclonic tracks into the area may originate in latitudes from Alaska southward to Washington and Oregon. These air masses contribute most of the precipitation total to the area.

## 2.3 Subsurface and Bedrock Geology:

Precambrian basement formation may be encountered in the study area at a depth of about 1770 feet (540 metres), although this depth depends to some extent upon topographic considerations (Amoco, 1974). The Devonian stratum overlying the Precambrian is a granitic sandstone, grading upward into shales and evaporites. The upper Devonian section is represented by the Methy Formation. This is a limestone formation, capped by a porous dolomite which constitutes a major regional aquifer. The middle Devonian section consists of the

Muskeg Formation, a 150 foot (fifty metre) thickness of anhydrite and dolomite. The Upper Devonian Period is represented by the Waterways Formation, comprised of interbedded shale and limestone, which is 400 feet (130 metres) in thickness (Carrigy and Kramers, 1973).

The formations of the Lower Cretaceous Period form the bedrock of the study area. Although not outcropping in the study area, the quartz sandstones and interbedded siltstones of the McMurray Formation are perhaps the most important formation in the region due to their impregnation with asphaltic oil. Members of this 250-300 foot (75-100 metre) thick formation contain the anticipated production horizons for the Amoco in-situ experimental plant at Gregoire Lake. Development of commercial in-situ production in the study area may be considered likely in the future, although none is presently planned (Amoco, 1975).

The bedrock nearest to the surface in the study area consists of three Lower Cretaceous formations. The north-eastern portion of the study area is underlain by the Clearwater Formation, primarily a shale of about 260 feet (80 metres) in thickness. The remainder of the area below approximately 1650 feet (500 metres) in elevation is underlain by the shales and sandstones of the Grand Rapids Formation. The Stony Mountain Plateau and the escarpment along its northern edge are underlain by the Joli-Pelican Formation. This formation is Pleistocene in origin, the contact with the Grand Rapids Formation being and erosional unconformity. The Joli fou-Pelican is composed mainly of shales and sandstones (Amoco, 1974; Bayrock and Reichen, 1974;

Carrigy and Kramers, 1973).

## 2.4 Surficial Geology:

The surficial geologic deposits in the Gregoire Lake area are primarily glacial in origin. Generally, the lowlands surrounding the lake have surficial deposits which are lacustrine in origin. The escarpment face and plateau are overlain by till and mixed glacial and bedrock materials. In addition, the slightly elevated areas east and northeast of Gregoire Lake are covered by till. Throughout the study area are sections of both organic deposits and alluvium.

The glaciolacustrine deposits are predominant in the area west and north-west of Gregoire Lake and in the lowlands between Surmont Creek and Gregoire Creek. This material has been described as bedded clay and silt with minor sand constituents in an area of fairly level topography (Bayrock and Reimchen, 1974). There are some areas, evident along roadcuts near Gregoire Lake Provincial Park, which have some gravel components (personal observation, 1975). These deposits are generally quite thin. The scattered pebbles and gravels, along with what appear to be beach ridges along the foot of Stony Mountain, indicate that this zone may have been the shore area of a pro-glacial lake.

The area of slightly high relief along the north-eastern and eastern shores of Gregoire Lake (including the Anzac townsite) is largely covered by Stony Mountain Till. This has been described as an

area of hummocky moraine composed of loam with numerous pebbles and boulders (Bayrock and Reimchen, 1974). Local relief in this area of till and bevelled till is not as great as in some other till-covered portions of the study area, but it still varies significantly from the low relief of the surrounding lacustrine deposits. Some additional deposits of Stony Mountain Till may also exist in the area between Gregoire Lake Provincial Park and Culvert Creek. These may be variations of the glaciolacustrine deposits showing some alteration in composition and topography near the margins of the lake.

The face of the escarpment which defines the northern limit of Stony Mountain is also covered by the aboved described Stony Mountain Till; in addition, a large percentage of the surficial geology on the scarp face consists of slump features described as mixed bedrock and glacial materials. In general, the slump areas are found in situations with locally steep slopes, whereas the till-covered sections of the escarpment lie in more homogenously sloped areas.

Two types of surficial deposits have little genetic relationship to the others in the area. The first of these is a broad category of organic deposits. These muskeg or swamp areas are found scattered throughout the area wherever relief is low. Especially promiment are those areas of muskeg associated with Surmont Lake and the other lakes in the upper drainage basin. Of particular interest in this study are the alluvial deposits associated with the channel of Surmont Creek. Bedded silt, sand and clay originating from the escarpment have been deposited along the watercourse in the middle portion of the basin. An extensive zone of similar alluviation has

been mapped along the foot of the escarpment and at the mouth of Surmont Creek. Numerous stream channels and ox-bow scars suggest the shifting nature of Surmont Creek in its lower reaches in the past.

Although the surficial geology of the study area is complex, some broad generalizations can be made. Lowland areas around the present Gregoire Lake are likely the result of meltwater lake deposits at the face of a receding or stagnant glacier. In contrast, the Stony Mountain Plateau shows evidence of mechanical deposition by the glacier, with till and morainal deposits being predominant. The escarpment face deposits are extremely complex, with glacial and bedrock material having been altered by several agents, most importantly slumping and erosion and deposition by Surmont Creek. Organic deposits exist in relation to topographic influences rather than geologic associations.

## 2.5 Hydrogeology:

The Athabasca region is a natural groundwater discharge area for much of the province (Hitchen, 1963). A more extensive hydrogeologic survey has recently been concluded which included the study area (Ozoray, 1974). However, the data available did not, in the opinion of the surveyor, merit construction of maps at a scale more definitive than 1:250,000. Cross-sectional hydrogeologic transects were constructed on both an east-west and north-south axis through or very near the study area.

Water quantities available from fround water sources appear to be quite limited in the Gregoire Lake area. Flow from formations

near the surface (with one exception) cannot be expected to exceed twenty-five IGM[1] (0.1 $M^3/m$)[2], and in most will be much less. Total dissolved solids range between 1000 and 3000 ppm (parts per million), constituted mainly of carbonates, bi-carbonates, sodium and potassium.

Ground water under the Stony Mountain Plateau shows some departure from this pattern. Well yields in this upland area are expected to range between twenty-five and 100 IGM (0.1-0.5 $M^3/m$). Quality is also somewhat superior to that of groundwater from the lower areas, having generally the same proportion between the constituents, but with less than 1000 ppm dissolved solids (Ozoray, 1974; Amoco, 1974).

The Devonian stratum underlying the study area appear to have the potential for production of somewhat greater quantities of groundwater, also being classified in the twenty-five to 100 IGM (0.1-0.5 $M^3/m$) yield range. However these stratum have not been investigated by actual field measurements for the study area. It seems unlikely that the groundwater from these formations will be of a useful quality for most purposes, considering the presence of the same evaporites contributing to severe salinity problems further to the north (Curry et al., 1975).

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[1] Imperial Gallons per Minute.

[2] Cubic Metres per Minute.

## 2.6 Hydrology:

Dominating the hydrography of the study area is Gregoire Lake, with an elevation of approximately 1560 feet (475 metres) above sea level. The lake is relatively shallow, apparently not exceeding forty feet (twelve metres) in depth. (An official lake survey has not been conducted for Gregoire Lake. However, during the course of depth/temperature investigations, very few measurements in excess of thirty feet (ten metres) were evident. This information, in addition to extensive weed growth throughout most of the lake, strongly support the above estimate.) The surface area of the lake is approximately 10.5 square miles (27.0 square kilometres). Gregoire Lake is drained near the south-east corner by Gregoire Creek.

The portion of the basin surrounding Gregoire Lake on the east, north and west sides is very narrow. This relatively small area does not contribute a significant portion of the total basin run-off. Several small lakes and sloughs exist along these margins of the lake, but in general drainage is good in this portion of the basin. In contrast, the area to the south of Gregoire Lake is much more complex in its hydrology. Apart from the tributaries entering the lake, there are a number of small sloughs and one small lake in this area. (This small lake is discussed more fully in section 5.3.) Muskeg and swamp exists in significant portions of the southern lowlands between the lake shore and the foot of the escarpment. This muskeg and the ditches along the road into Anzac show considerable fluctuation in water level

during the course of the year.

There are two significant tributaries flowing into Gregoire Lake, both entering from the south side. The major one is Surmont Creek, originating on the Stony Mountain Plateau. Approximately 9.1 miles (14.6 kilometres) in stream-length, Surmont Creek is meandering for much of its length, but is relatively straight where it is incised into the escarpment of Stony Mountain. In its lower reaches it flows through Indian Reserve 176, very close to the Amoco Gregoire Lake Experimental Site (Figure 1.2-1). Deltaic deposits have been built up over an area around the mouth of Surmont Creek, extending for several hundred yards (several hundred metres) into Gregoire Lake. This creek drains the northern-most portion of the Stony Mountain Plateau.

The only other major tributary flowing into Gregoire Lake is a small un-named creek, called Culvert Creek for the purposes of this study. This creek drains a portion of the escarpment in addition to some flat areas south-west of the lake and a small un-named lake (again, refer to section 5.3) just south of Indian Reserve 176A (Figure 1.2-1). Deltaic deposits appear to be absent for the most part at the mouth of this creek. It should be noted that during high water periods, Culvert Creek and Surmont Creek sometimes become connected via the drainage ditches and culverts along the Anzac road; during these periods Surmont Creek overflow contributes to the flow of Culvert Creek.

The Stony Mountain Plateau, in addition to being part of the catchment for Surmont Creek, contains several other significant

hydrologic features. Most noteworthy of these are the many small lakes and ponds in the area. Although more than a dozen of these exist and the total surface area is moderately large, none of the lakes exceeds one half of one square mile (one square kilometre) in surface area. Most of the lakes are connected to Surmont Creek via a rather convoluted network of streams, swamps and channels. Extremely large portions of the plateau are also in muskeg, both treed and open (see Chapter IV). Watershed boundaries in this area are unclear; precipitation to the south and west of the Surmont Creek drainage area flows into the Hangingstone River, that to the south and east flowing into either Gregoire Creek or the Christina River.

Gregoire Creek, although by definition outside the Gregoire Lake drainage basin, is significant to the area, as it drains Gregoire Lake. Gregoire Lake is a meandering stream, draining via the Christina River into the Clearwater River and eventually into the Athabasca River at Ft. McMurray. Near the present headwaters of the stream a control structure and fish ladder have been built; this will soon be the exit for waters from Gregoire Lake, contingent upon filling of the old bridge gap. (The hydrology of the area is treated in depth in Chapter III).

## 2.7 Soils:

Soils in the study area are of the Grey Wooded and Gleisolic groups. In muskeg areas, the soils are organic. Grey Wooded soils in

northern Alberta are not particularly noted for extensive development of the A horizons (Bentley, et al., 1971) and in the study areathis is especially true. Although road cut and ditch profiles indicate that the soils are more developed in the better drained localities, in general the Ah horizon does not exceed one inch in thickness with the Ae horizon being exceedingly thin. This is probably due in part to climatic considerations, but also to the parent material, a fairly sandy glacial till. In the lowland areas, surficial geologic studies indicate that more of the parent material is of lacustrine origin; consequently less gravel and more clays may be expected to be present. It is noteworthy that, owing to the extremely shallow development of the soils in the Gregoire Lake area, even minimal disturbance of the surface layers can result in severe potential for damage by surface erosion.

The potential for agricultural use in this area is extremely limited; at present only some livestock are maintained in the study area. Forage crops and improved pasture are likely to be the most practical combinations for more intensive agricultural use in the area. Even these uses will be subject to the aforementioned extreme climatic and topographic limitations. Use of muskeg areas is, of course, quite minimal.

Some areas of permafrost may exist in the area, although this has not been confirmed by direct observation. Some evidence of frost-generated features has been documented in a recent aerial survey of the area, so a strong possibility of permafrost can be inferred (Shelford,

1976). It has been suggested that permafrost presence is governed largely by factors related to air temperature (Brown, 1962). Presence of permafrost within the study area could be dictated by a number of factors; these might include latitude, continentality, altitude, vegetative cover, drainage and aspect. Although the study area is located at the extreme margin of discontinuous permafrost as defined by Brown and others, it would not be unreasonable to expect some small areas of permafrost to exist on the north-facing slopes of Stony Mountain or on the plateau itself. More likely that permafrost would be the existence of areas of discontinuous permafrost or climafrost[1] in similar situations (Williams, 1962). In either case, a very minor portion of the study area would be affected.

## 2.8 Flora:

The Gregoire Lake area lies within the zone of mixed boreal forest. A very small percentage of the area has been altered by the activities of man, these areas for the most part being in rough pasture or hay meadows along Surmont Creek. Some areas around the Anzac townsite, Gregoire Lake Provincial Park and at the Amoco Gregoire Lake Experimental Site have been cleared; these areas remain unvegetated for the most part. Fires have had some influence in the study area in the past, but no recent burns have occured.

Five broad vegetation groups have been defined for the area (Amoco, 1974). The wetland group is composed of marsh plants, moss-

[1]Discontinuous permafrost or climafrost is year-round freezing of the ground in some years, but not in others.

sedge fens and black spruce-*Sphagnum* bog communities. The upland treeless communities consist of the meadow and tall shrub communities. The upland deciduous group includes the white birch, aspen poplar and balsam poplar communities. Upland spruce groups consist of both white spruce and black spruce communities, although it should be noted that the transition areas between white and black spruce are often unclear, as well as the zones between black spruce and treed muskeg areas. The fifth group is the upland pine group, consisting of the jack pine community of plants. These vegetation groups bear important relationships to soil moisture storage capacity, and are further categorized in that respect in Chapter IV.

## 2.9 Fauna:

Animal life in the study area is quite varied. However, a complete listing of the fauna is beyond the scope of this study. Some of the species present are important to the human occupants of the area, and thus merit special attention.

Aquatic and semi-aquatic life in the area is abundant. Several species of sport fish inhabit the study area, including northern pike (*Escox lucius*), walleye pike (*Stizostedion vitreum*), cisco (*Coregonus artedil*), lake whitefish (*Coregonus clupeaformis*) and yellow perch (*Perca flavescans*). Gregoire Lake contains all of the above mentioned species, being rated by the Canada Land Inventory classification system as having a Class II capability for sport fishery. Surmont Creek is also rated as Class II, the important species for angling

being grayling (Thymallus arcticus). The higher lakes in the watershed, Surmont Lake being the most important of these, are also considered to have some capability for sport fishery.

Waterfowl are abundant in the area, with numerous species of ducks, geese, teal, grebes, mergansers, loons and shorebirds present. The lake does not appear to have more than a moderate importance as a staging area. Among the upland game birds, spruce grouse, ruffed grouse and sharp-tailed grouse are present. Many other species of birds of less direct interest to man also inhabit the study area.

Ungulates exist throughout the study area; Canada Land Inventory categories for the study area are III and IV. Most important of the ungulates is the moose. A number of these animals exist primarily on the Stony Mountain Plateau. Some woodland cariboo may also inhabit this area, especially during the winter months when the area becomes important as a winter feeding ground. Deer (Odocoileus spp.) also inhabit most of the region.

Furbearing animals are not of recreational importance, but are of some traditional and financial significance to the human population of the area. Based on 1971-72 and 1972-73 trapping records, there appear to be perhaps a dozen species of fur-bearers present. Five of these are trapped in relative abundance: beaver, lynx, varying hare, red squirrel and muskrat (Amoco, 1974).

2.10 History:

The early history of the Ft. McMurray region is linked to the activities of hunters and trappers, both native and white. The Indian tribes of the area were the Cree and the Chipewyan, both of which are still represented. The primary activities of these somewhat nomadic groups consisted of trapping and hunting, supplemented by fishing. In 1778 Peter Pond confirmed the existence of what became known as the Methy Portage. Since early transportation and exploration in the region was limited to canoe (and later to York boats), this divide between the Churchill and the Peace-Athabasca river systems was the gateway to north-western Canada. The confluence of the Athabasca River and the Clearwater River became an early point of contact between the native population and Europeans, leading to the establishment of Fort McMurray. The fur trade possibilities soon drew the Hudson Bay Company into the area, later followed by the Northwest Company. The activities of the trappers and trading companies dominated the history of the area through the nineteenth century (Chalmers, 1974).

As transportation to the north became more important, the trans-shipment facilities in the Ft. McMurray area became more active. The completion of the Northern Alberta Railroad to the settlement of Waterways in 1916 contributed to the barge traffic moving down the Athabasca River. Oil exploration in the far north continues to be a major source of freight for the barges heading down the Athabasca-Peace-Mackenzie route. Freight from truck traffic has become increasingly important to Ft. McMurray since the completion of the paving of Highway 63 in 1975 cut

travel time from Edmonton to five hours (Camp, 1974).

The history of the oilsands in the Ft. McMurray region begins as early as the exploration of Pond and that of Alexander Mackenzie in 1792. The latter first described the oilsands and its use by the Indians in tarring their canoes. The oilsands remained somewhat of a geologic curiosity until the latter half of the 1800's, when the first attempts at commercial recovery were conceived. The milestone in recovery technology was the development of a hot water extraction process by Dr. K.A. Clark in the 1920's. The next several decades were devoted to many attempts at larger scale strip-mining operations, culminated in 1967 when the Great Canadian Oil Sands plant came on stream (Carrigy and Kramers, 1974).

More recently, the major focus of activity in the area has been the 125,000 barrel per day Syncrude project. Slated to come on stream in the late 1970's, this consortium of private corporations and governments will have a capital expenditure in the neighborhood of two billion dollars. Owing to this huge investment requirement and other reasons (see Section 6.1), it now seems likely that the next major project to come on stream will be based upon in-situ techniques rather than strip-mining and processing.

There are a number of human influences within the Gregoire Lake area. The most prominent of these is the settlement of Anzac, with a population of somewhat over 200 persons. Settlement density is not great, the population being distributed between the lake shore and the tracks of the Northern Alberta Railroad. The Anzac Forestry Camp is located

just east of these tracks. It served as the field base for this study. Road surfaces throughout are dirt or gravel.

The Stony Mountain Indian Reserve covers two portions of the study area; the most important of these is the larger area within the drainage of Surmont Creek. This area has been altered by the clearing of some brush and forest for the creation of rough pasture or hay meadows. Several habitations are scattered within this area. Population density within the Indian Reserve is extremely low, increasing slightly with proximity to Gregoire Lake and the Anzac road. Many of the Indians live outside the reserve in Anzac. The only major use to which this land is presently put is extensive grazing.

Located within the Indian Reserve is the Amoco in-situ experimental site. Established in 1973, this is one of the first attempts at recovery of oil from the Athabasca Oilsands by other than mining and processing techniques. The site is located on the lower levels of the escarpment, and it includes not only the experimental area itself, but the associated storage and living areas, roads and a small air strip. (See Section 2.11.)

Gregoire Lake Provincial Park is located on the western shore of Gregoire Lake. A variety of facilities is present, including camp sites, picnic areas, hiking trails, boat launching and docking facilities, a swimming beach and a parking area. Use of this park has risen dramatically in the last few years, probably because it is the only provincial park within a reasonable distance of the rapidly growing town of Ft. McMurray. Demand has increased beyond the present capacity

of the park, leading to extensive use of the turn-outs along the southern shore of the lake as well as the camping, picnic and swimming facilities adjoining Anzac at the eastern end of the lake (Hilsen, 1975). Present plans call for expansion of recreational facilities around Gregoire Lake (Landals, 1975).

## 2.11 Amoco Gregoire Lake Experimental Site:

Initial development of the Gregoire Lake site began in 1959 when Amoco (then Pan American Oil) initiated their experimental work with the partial combustion method of in-situ recovery of the Athabasca oilsands (Carrigy and Kramers, 1974). Sporadic progress since that time resulted in the establishment of an experimental plant in 1973 (Amoco, 1974). With the recent addition of funding from the provincial government, expansion to the pilot plant stage can be anticipated in the near future, with commercial scale production to follow (Edmonton Journal, June 11, 1976).

The manner and sequence of development on the Amoco acreage will be of the utmost importance in maintainence of a desirable watershed quality. Development of the Amoco acreage will proceed generally in the following stages:

1. Development of access roads into the area and into specific sites within the development area. At present, this is provided by the Stony Mountain Forestry Road, but in the future, more roadways will be needed to gain access to

well sites.

2. Clearing of vegetation down to mineral soil. This will be necessary on all drilling pads and support sites. Approximately ninety per cent of the development area will be cleared, with each well site being about one acre (0.4 hectares) in size.

3. Drilling of injection and recovery wells, installation of process equipment, utilidors, etc. There is a minor hazard of environmental damage from drilling procedures that might result in mud spills, etc. This damage would be of a very localized nature.

4. Operation of the wells during recover procedure. (See Section 6.3). Limited reclamation of the drilling pads and access routes could be undertaken during this phase and the previous phase.

5. Recovery of equipment (for re-use in other areas). After this final production phase, a final reclamation phase would be undertaken to achieve the desired post-development environment.

It is evident from this development and reclamation sequence that substantial initial disturbance over a widespread area will occur. Prolonged disturbance of a lesser nature, as well as partial reclamation, will take place during the production life of any set of wells. (This production life is estimated by various companies to be in the range of fifteen to twenty years.) This will be followed by salvage of equipment

and final reclamation.

The major human impact in the Gregoire Lake area will be directly linked to future increases in oilsands activities. A great many of the impacts upon the environment will be results of human activity peripheral to the actual development of in-situ recovery. These impacts are likely to become more severe as the regional population increases. Analysis of these spin-off effects of activities associated with development but not directly involved is beyond the scope of this study. Those resulting more directly from in-situ development are treated in Chapters V and VI.

# Chapter III

## Hydrology

### 3.1 Regional Hydrology:

The hydrology of the Athabasca Oilsands region is dominated by the Athabasca River. The period of record for streamflow of the Athabasca River at Ft. McMurray is from 1957 to the present. Yearly mean discharge is about 17 million acre-feet per year (2,097,000 hectare-metres per year), with a deviation of as much as five million acre-feet per year (6.7,000 hectare-metres per year) from this mean. Mean daily discharge is about 23,500 cfs (665 $M^3/s$) for the same period of record. However, deviation from this mean is the rule rather than the exception. High water marks, related to mountain snowmelt, are usually reached in early summer. A maximum monthly discharge also occurred during July 1971: 96,700 cfs (2738 $M^3/s$). Low flow characteristics prevail during the winter months, the record daily low flow of 3,410 cfs (97 $M^3/s$) having been recorded on February 3, 1964. The record minimum monthly discharge of 3,730 cfs (106 $M^3/s$) also occurred during the same month (Environment Canada, 1974). The river is incised about 200 feet (60 metres) in the Ft. McMurray region, with any flooding usually the result of ice damming in the spring break-up period.

Water quality in the Athabasca River varies seasonally, but is generally low in solutes (less than 400 mg./l.) and high in suspended sediment. Turbidity ranges from 10 Jackson Thermal Units (JTU) in the winter months to 650 JTU during high flow periods.[1]

[1] The Jackson Thermal Unit is a measure of the opacity of water as reflected by suspended sedimenet. Data in mg./l. were unavailable.

Most of the flow of the Athabasca River at Ft. McMurray originates outside of the Athabasca Oilsands region, so water quality condtions in the river are not at present significantly a function of watershed condition within the region itself. Generally, the quality of the water in the Athabasca River at Ft. McMurray is good for most uses, although some settling may be required for municipal and industrial uses.

Several smaller rivers and streams in the region have been gauged for varying periods of time. The longest period of record is that of the Clearwater River, of which Gregoire Creek is a minor tributary via the Christina River. Others include the Steepbank River, Firebag River, Poplar Creek and Beaver Creek, with others recently being added. The Clearwater River gauge has been recording since 1958, while the others mentioned above have been in operation since 1972. No attempt has been made to classify these rivers and streams relative to their basin characteristics since the hydrology of this region has only recently come under serious study. Of particular interest <u>for this study</u> is the gauge located on the Hangingstone River at Ft. McMurray, in place since 1965. Although the point of gauging is somewhat removed from the Gregoire Lake Basin, the Hangingstone River Basin immediately adjoins the Gregoire Lake Basin along its western margin (Figure 1.2-1). Many of the topographic, vegetative cover, soil and other relationships are similar in these two basins and are more fully discussed below (Section 3.2).

Water quality and flow characteristics are not constant between the above rather widely dispersed streams; in spite of this,

it is possible to suggest some common characteristics. Streamflow in the Ft. McMurray region is characterized by extreme seasonal variation, with discharge in some of the smaller streams (eg. Beaver Creek) dropping to nil during some days in the winter months. Yearly variation is also great, with discharge in some years being three times that in others. This variation appears to increase in inverse proportion to the mean discharge of the streams with records. Water quality also varies from season to season and from stream to stream. In periods of high flow the streams generally have a higher sediment load, while dissolved solids loading is greater during the low flow stages in streams having significant year-round flow. This is apparently the result of groundwater discharge in the Ft. McMurray region being higher in dissolved solids than surface run-off. Snowmelt run-off (often from outside the region) is quite low in solutes; streamflow generated as a result of snowmelt run-off will quite likely result in less solute loading that that resulting from rainfall. The major exception to these general patterns is the surface run-off originating in areas of muskeg. Dissolved solids in many of these areas are in higher concentrations, and the muskegs are generally characterized by water which is low in sediment (clear) but has a distinct brown coloration resulting from high iron ion concentrations. Water originating in muskeg areas is also likely to have a high biological oxygen demand (BOD) and to be relatively acidic as a result of the high organic content of muskeg soils. The quality of this run-off for wildlife production, especially fisheries, is poor.

Lakes in the region vary considerably in size and quality. The Athabasca River terminates in the Peace-Athabasca Delta at the south-western end of Lake Athabasca. The water quality as it relates to the ecology of Lake Athabasca and the delta area has been extensively documented (Proceedings of the Peace-Athabasca Delta Symposium, 1971). Water in Lake Athabasca and the lakes associated with the delta vary somewhat in quality, but most are highly productive lakes involving a large range of wildlife. Lakes more local to Ft. McMurray are considerably smaller, being generally less than twenty square miles (fifty square kilometres) in area. The water quality is usually a function of depth and through-flow. Some, such as Namur Lake (located to the northwest of Ft. McMurray), are of high quality and considered excellent sites for sport fishing and other recreation. However, these lakes are for the most part inaccessable by road. Other lakes, such as Gordon Lake, suffer from extensive weed growth during the summer, but are cited as good staging areas for waterfowl (Environment Alberta, 1973). Some smaller lakes, including several on the Stony Mountain Plateau, are felt to have good recreational potential for boating and fishing.

## 3.2 Hydrology of the Gregoire Lake Basin:

The major hydrologic feature of the study area is Gregoire Lake, having an area of approximately 10.5 square miles (27.0 square kilometres). The natural level of the lake is about 1,560 feet (475.5 metres) above sea level. A lake level gauge has been present in

Gregoire Lake since 1967, where occasional readings recorded during high and low water periods have been obtained. Since 1967, lake levels have dropped to a minimum of 1559 feet (475.2 metres), while the maximum recorded level has been 1562.5 feet (476.3 metres). The area of Gregoire Lake is not significantly affected by the fluctuations in water level due to the rather steeply sloping shores. The lake is relatively shallow, probably not exceeding forty feet at the deepest point. Soundings taken during a preliminary temperature survey of the lake indicate the greater portion of the lake to be less than twenty feet (6.5 metres) in depth. The lake bottom is generally sandy, with good beaches existing near Anzac and at the provincial park. Gregoire Lake is drained by Gregoire Creek near the south-east end of the lake, while the two major tributaries, Surmont Creek and Culvert Creek, enter along the southern shore (see Figure 1.2-1).

Surmont Creek has the greatest yearly discharge of the tributaries of Gregoire Lake. Periodic gauging during the study season showed a peak flow for 110 to 120 cfs (3.4 $M^3/s$) occuring during the second week in September. However, no flow at all was observed during the first week of the preceding April. Auger bores during this time showed the formation of frazil ice throughout the cross-section of the stream, with some flow through this relatively porous ice. This flow was not judged to be in excess of one or two cfs (0.04 $M^3/s$). Owing to the freezing of Surmont Creek to the bed, initial flow during the spring took place over the surface of the ice. However, this may not be the case in all years.

Surmont Creek does not have a permanent gauge, but periodic readings were undertaken during the study season. The point of gauging was the bridge where Surmont Creek crosses the Anzac road (Figure 4.4-1). These gauging periods were coordinated with periods of intense precipitation in an effort to determine peak flow characteristics. Under normal summer flow conditions, Surmont Creek appears to have a base flow of about 30-40 cfs (about one $M^3/s$). Flow during years previous to the past several may have been substantially lower, since the summer of 1975 was relatively high in precipitation and soil moisture storage supplies from previous years were high. Surmont Creek was observed to have rapid response to storms greater in magnitude than 0.5 inches (125 millimetres) of precipitation, or to a series of days with lesser amounts of precipitation. However, this response was not directly proportional to the magnitude of the storm. This is probably related to a number of factors. The large area of the Surmont Creek drainage area located on top of the Stony Mountain Plateau consists of dead ice moraine and muskeg, and both have high detention storage. This quite likely has the effect of delaying and moderating run-off peaks. The distance from the point of gauging to the portion of the basin collecting the majority of the run-off, in conjunction with the meandering nature of the stream in its lower reaches, could also result in a considerable basin lag. In addition, the several lakes along Surmont Creek and on its tributaries above the escarpment would also limit rapid storm response. These factors are not present to as great an extent in either the Culvert Creek drainage area or for the Hangingstone River

basin above Ft. McMurray.

Culvert Creek was gauged where it exited from a large culvert under the road between Highway 63 and Anzac (Figure 4.5-1). Accurate guaging is generally possible from culverts, but in this case deformation of the inlet made conventional discharge calculations for corrugated culverts impractical. (While the outlet was circular, with a diameter of five feet (1.5 metres), the inlet had been crushed to a height of about three feet (one metre)). Normal summer flow in Culvert Creek in 1975 was about 15-20 cfs (about 0.5 $M^3/s$), but response to storms sometimes increased this to nearly as great a discharge as was observed in Surmont Creek. During the storm period which occurred during the first two weeks in September, the capacity of the culvert was exceeded; water levels behind the dam created by the road rose to within several inches (about ten centimetres) of the road surface before receding. During periods of heavy run-off such as those noted above, Culvert Creek received some flow from Surmont Creek via a net work of ditches and culverts along the road, although this flow did not exceed several cfs (0.1 $M^3/s$) and ceased completely after water levels receded.
The characteristic difference between Surmont Creek and Culvert Creek is in the rapidity of flow response to storm run-off. Culvert Creek does contain a small lake and some muskeg area in the lower portion of the drainage area. However, this amount of detention storage would not be likely to suppress rapid run-off relative to the extensive detention storage capability of the Surmont Creek basin. This was, in fact, borne out during the several major storms occurring during the study

Photo 3.2-1: Surmont Creek below bridge. (April, 1975)

Photo 3.2-2: Culvert Creek above culvert. (April, 1975)

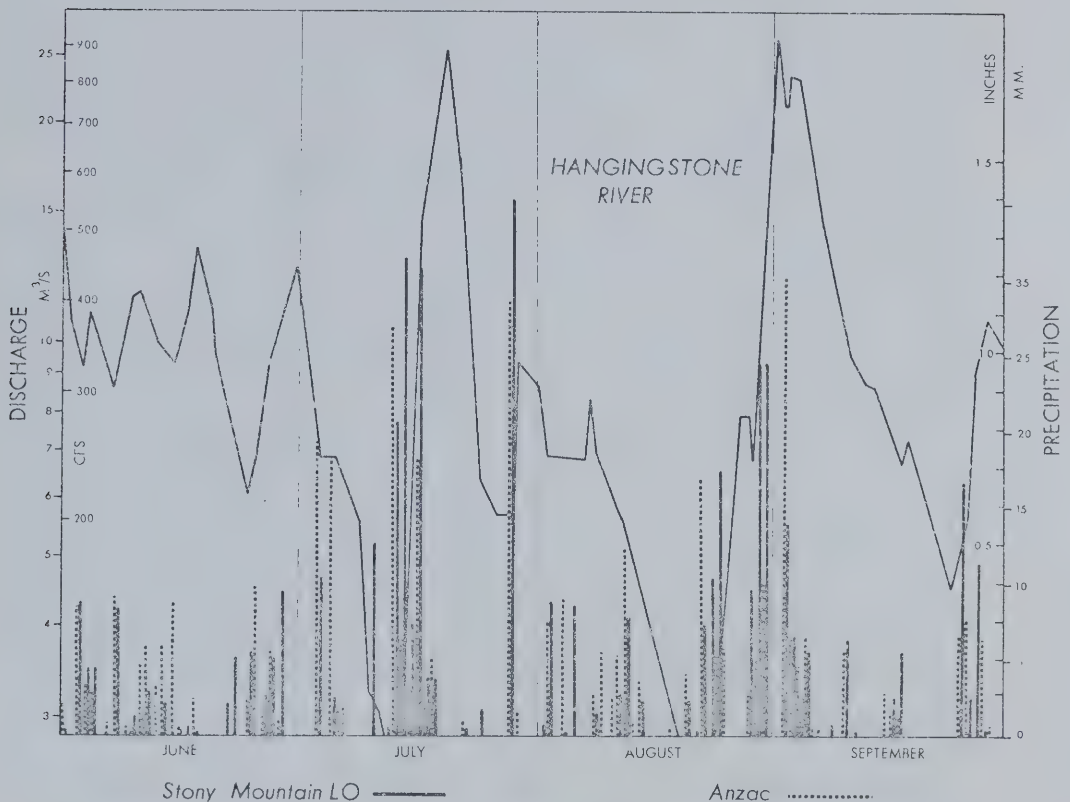
Photo 3.2-3: Surmont Creek near Amoco Site. Note slumping bank on right. (July, 1975)

Photo 3.2-4: Surmont Creek at high stage. Flow in roadside ditch is west toward Culvert Creek. (May, 1975)

season.

Gauging of Gregoire Creek was possible at a much earlier date than was the case for either Surmont Creek or Culvert Creek, since Gregoire Creek has some flow throughout the year. This flow probably results in part from the reservoir capacity of Gregoire Lake, in part to the temperature of the reservoir water, and in part from local groundwater flow. Initial gauging was undertaken on April 2, 1975, before the spring snow-melt, to establish a base flow rate. On this date, and for several weeks afterward, the rate of flow was constant at 13-15 cfs (0.36-0.42 $M^3/s$). It is difficult to determine to what degree this figure is representative of other winters due to a number of factors. Lake levels during the winter of 1974-75 were described by local residents as being substantially lower than usual. (The lake level gauge was not in operation at this time.) This would suggest that the flow in 1974-75 was less than normal. In addition, snowfall during the winter was extremely low, with the consequent low snow-catch exerting little pressure on the ice. If heavier snowfalls had been experienced, then greater flows could have been anticipated. A complicating factor exists in this situation, however. Owing to the lack of snow-catch and consequent lack of insulation of the ice against low air temperature, deeper formation of ice occurred. Observations near shore at the outlet from the lake indicated an ice thickness of two to three feet. The thickness was described as unusually great by local ice fishermen relative to the thickness experienced in other

FIGURE 3.2-1 PRECIPITATION AND STREAM HYDROGRAPH




1975 data.

years. This thickness undoubtedly contributed to the late break-up date of Gregoire Lake in 1975, the ice leaving the lake during the last week in May and the first week in June. Again, conversations with local residents indicated that this was an unusually late date.

Discharge maxima occurred in Gregoire Creek during mid-July, when a rate of 125 to 150 cfs (3.6 to 4.3 $M^3/s$) was observed, and again in early September, when a flow of nearly 200 cfs (5.7 $M^3/s$) was estimated from the stage (Figure 3.2-1). Considering the unusual wetness of the summer of 1975 (see Chapter IV), it is noteworthy that the run--off maxima were achieved during periods of prolonged rainfall and not directly from snow-melt. Precipitation on the order of three to five inches (750-1250 millimetres) during a period of a week resulted in heavy run-off (Figure 3.2-1). Single storm occurrences (for example, the 1.38 inches (350 millimetres) received on July 26) did not result in the rapid stage rise of the gentler but longer duration rains of late August and early September. This is at least partially owing to the reservoir capacity of Gregoire Lake, but as was discussed previously, similar characteristics were observed in Surmont Creek. The major cause of this regime pattern is probably the depletion of soil moisture detention storage during the periods between precipitation, with the lag or absence of streamflow response being largely a result of the recharging of these storage levels, groundwater and interflow.

The Hangingstone River hydrograph data (Figure 3.2-1), although from outside the Gregoire Lake drainage basin, are useful in this study because of the proximity of this basin to the study area (Figure 1.2-1).

There are a number of physiographic factors which will cause the flow characteristics of Gregoire Creek, Surmont Creek and the Hangingstone River to differ. Several of the factors relating to the geometry of the basins are in evidence. The Gregoire Lake Basin, as a result of a combination of shape and elevation, has a large percentage of its drainage area at a higher elevation. This high elevation, in addition to the presence of large areas of muskeg and numerous small bodies of water, results in both a high yield potential and a high detention storage. The relatively rapid fluctuations in the Hangingstone River hydrograph reflect the absence of as much detention storage in that basin. Some channel factors are also reflected in the flow characteristics. The meandering channels of the streams in the Gregoire Lake Basin would tend to moderate storm peaking more than is apparent in the Hangingstone River Basin. The lower slope and greater channel storage capacity of Surmont Creek and Culvert Creek are likely the causative factors of this moderation.

There are also some other variables which may be broadly classified as climatic factors (Chow, 1964). One of the most important of these is the form in which the precipitation falls. A larger portion of the precipitation in the Gregoire Lake Basin is in the form of snow due to the greater percentage of the basin being located at a higher altitude. This altitudinal factor also results in longer maintainence of snow-pack into the spring. These snow-related factors, combined with an orographic precipitation increase over the same areas, result in greater yields and longer sustained flows. The rapid peaking that

might result from snow-melt at lower elevations is less evident and this contrast is accentuated because of the widespread presence of muskeg areas which have reduced potential evapotranspiration rates. Although there are some physiographic and climatic factors (eg. the longer channel length of the Hangingstone River) which tend to modify the above mentioned contrasts, it is clear from the resulting hydrographs that these are the dominant factors affecting flow regimes in the Hangingstone River Basin and Gregoire Lake Basin (Appendix B).

## 3.3 Water Quality:

Several water quality parameters were observed and recorded for Gregoire Creek, Surmont Creek and Culvert Creek as they related to seasonal and daily fluctuations in stream discharge (Tables 3.3-2, 3.3-3 and 3.3-4). Initial testing was completed over a wide spectrum for samples collected on June 13, 1975, with little deviation from expected results. The water quality parameters tested are within the range to be expected in the Ft. McMurray region. It was felt, therefore, that further testing could be limited to suspended sediment, dissolved solids (resistivity), and temperature. Suspended sediment was used as an indicator of upstream erosion and of potential sedimentation in Gregoire Lake. Dissolved solids were used as a general indicator of water quality, but also as suggestive of the significance of run-off from muskeg areas relative to the total discharge (see also Chapter IV). Lower temperature is a general indicator

of snow-melt run-off, and also of early season run-off from the colder muskeg areas. Conversely, the heating of the areas of standing water will provide warmer flow later in the season. Regional groundwater is apparently greatly outweighed by inflow from upstream areas, considering the very low amount of solutes in the surface water supply.

There is some variation in water quality between the large and small streams of the Ft. McMurray region (Table 3.3-1). The most evident of these difference is the greater sediment load carried by the Athabasca River and Clearwater River during some seasons. In contrast, the solute load in the smaller streams of the Gregoire Lake area are greater. (These differences would likely be more accentuated if there was flow throughout the winter in the smaller streams.) The major reasons for these differences are differences in sources of flow (mountain or shield snowmelt) of the larger streams which rise outside the region. These variations in water quality in the regions will be a factor in planning for future water needs, provided sediment load or solute loading are critical factors. The lack of dependable flow in the smaller streams, either during dry years or during winter freeze-up, may also be a factor. Conjunctive use of both local and larger stream flow may be desirable, especially if by re-using local supplies the disposal problems may be reduced.

Quality of flow in Surmont Creek is critical to a quality water supply for Gregoire Lake. Indications throughout the season were that Surmont Creek is turbid relative to other water bodies in the

Table 3.3-1: Regional Water Quality Parameters

| Parameter Tested | Gregoire Creek | Surmont Creek | Culvert Creek | Athabasca[2] River below Ft. McMurray | Clearwater[2] River |
|---|---|---|---|---|---|
| Sediment[1] | 17.0 | 81.1 | 41.7 | 3/865 | 61.0/149 |
| pH | 7.58 | 7.57 | 7.85 | 7.2/8.8 | 7.2/8.6 |
| Colour | 54 | 186 | 134 | 5/100 | 5/100 |
| Fe[1] | 0.17 | 1.37 | 0.55 | L.001/0.34 | L.001/0.310 |
| $SO_4$[1] | 11 | 9 | 13 | 8.8/55.6 | 5.9/25.2 |
| Total PO4[1] | .14 | .25 | .19 | .010/.033 | .010/.033 |
| Nitrogen | .50 | .56 | .48 | 0.6 | |
| Chloride[1] | nil | nil | nil | 0.6/40.5 | 1.7/81.0 |
| Turbidity (JTU) | 11 | 45 | 21 | 1.0/650 | 0.6/125 |

[1]All units are mg./l.

[2]Source: Environment Canada, "Water Quality Data", Alberta, 1961-73.

[3]Tested for June 13, 1965

Table 3.3-2: Conductance[1]

| Site | April 13 | April 23 | April 20 | May 16 | June 13 | July 18 |
|---|---|---|---|---|---|---|
| Gregoire Creek | 115 | 118 | 84 | 94 | 102 | 98 |
| Surmont Creek | 148 | 116 | 66 | 58 | 72 | 50 |
| Culvert Creek | 260 | 229 | 175 | 141 | 177 | 155 |

[1]All units are micromhos.

Table 3.3-3: Suspended Sediment[1]

| Site | April 13 | April 23 | April 29 | May 16 | June 13 | July 18 |
|---|---|---|---|---|---|---|
| Gregoire Creek | 5.6 | Ø | 9.7 | 12.7 | 17.0 | 23.5 |
| Surmont Creek | 12.6 | 23.1 | 3.0 | 61.4 | 81.1 | 46.5 |
| Culvert Creek | Ø | Ø | Ø | 2.9 | 41.7 | 1.3 |

[1]All units are mg./l.

Table 3.3-4: Temperature (in °C)

| Site | April 13 | April 23 | April 29 | May 16 | June 13 | July 18 | Sept 14 |
|---|---|---|---|---|---|---|---|
| Gregoire Creek | +4.5 | +4.5 | +5.0 | 6.5 | 11.0 | 14.0 | 17.0 |
| Surmont Creek | F | 0.5 | 0.5 | 5.0 | 10.5 | 14.5 | 18.0 |
| Culvert Creek | F | 1.0 | 1.5 | 5.5 | 11.0 | 15.0 | 19.0 |

study area. Turbidity in the two major tributaries showed a reading of 81 mg./l. (45 JTU) in Surmont Creek and 41.7 mg./l. (21 JTU) in Culvert Creek on June 13, 1975 (Table 3.3-2). This pattern was generally the same throughout the season. The high concentration of iron ions is also noteworthy in Surmont Creek (Table 3.3-1). It is higher than in either Culvert Creek or Gregoire Creek, and is quite high relative to other major streams in the region. This is undoubtedly due to the large muskeg area present in the southern portion of the Surmont Creek drainage. However, there is not a correspondingly great component of some other factors normally associated with high organic content; specifically, conductance figures for Surmont Creek are consistently lower than those for Culvert Creek (Table 3.3-2). The most likely explanation for this is a higher percentage of flow resulting from precipitation in Surmont Creek, with relatively less contribution from groundwater that is likely to be higher in solutes. Some of the other data are inadequate for conclusions to be drawn. Sulfates and phosphates are found in similar concentrations in both Surmont Creek and Culvert Creek. Given the above information, this might seem surprising, since Surmont Creek has the greater area of muskeg within its drainage. However, there is a significant drop in elevation between the major collecting portion of the basin and the gauging point. This vertical drop of about 800 feet (250 metres) would allow for significant oxygen replenishment of the stream and lowering of the BOD associated with the lessening of organic decomposition rates and consequent improvement in the over-all water quality. (There is

less than a twenty foot (six metre) difference in elevation and about one-half mile (0.6 kilometre) distance between the muskeg areas of the Culvert Creek Basin and its entrance into Gregoire Lake. Some of this muskeg area lies immediately above the point at which sampling of Culvert Creek was undertaken.)

Sedimentation in Gregoire Lake or its tributaries could be a critical factor in maintainence of water quality in Gregoire Lake, especially relative to the fisheries potential. As noted above, turbidity (suspended sediment) is high in Surmont Creek relative to Culvert Creek or Gregoire Creek. This is undoubtedly due at least in part to the rapidity of flow and consequently greater carrying capacity of Surmont Creek. There is also greater erosion in the steeper section of the stream in contrast to the limited erosion associated with the shallower gradient of Culvert Creek. Although sedimentation in the lower reaches of Surmont Creek is certainly not a problem at present, and suspended sediment figures are low by regional standards, the high slope of the middle sections of the streamcourse constitute a zone of active erosion. If stream discharge should increase, or become subject to rapid fluctuations, erosion in this zone could certainly be accentuated. The subsequent transport of the eroded material downstream and its deposition in the lower reaches of Surmont Creek or in Gregoire Lake would not enhance the current uses of either.

It is noteworthy that while Culvert Creek also drains a portion of the same high slope area, the suspended sediment in Culvert Creek is substantially lower than that in Surmont Creek. It is reasonable

to assume that the small lake just upstream from the point of guaging on Culvert Creek acts as a settling basin, just as the muskeg below the poorly developed drainage leading into this lake may function as a filter, excluding sediment carried down from the escarpment. If sedimentation becomes a significant problem at some future date, a trade-off between the lower quality of the dissolved constituents of Culvert Creek (resulting from muskeg) and the lower quality component of Surmont Creek resulting from suspended sediment (or bed load) could be made by utilizing the filtration capacity of the muskeg areas. This might involve channeling water from one basin to the other in the lower reaches of the streams. It should be noted that at present the water quality of both Surmont Creek and Culvert Creek is excellent for most uses by regional standards, and no remedial action of any sort is necessary.

Seasonal variation of water temperature in the Gregoire Lake Basin is marked (Table 3.3-4). During the winter months, all surface tributaries of Gregoire Lake are frozen, and do not discharge into the lake. Outflow from the lake via Gregoire Creek did not drop below 4.5$^{o}$C during the study season, and in all likelihood does not ever fall more than one degree C below this temperature. This temperature, when considered with the flow rates discussed earlier, is suggestive of at least some ground-water flow contributing to the maintainence of Gregoire Lake. This flow is probably local in origin, since the solute characteristics of regional flow do not appear to be a factor in the water quality of Gregoire Lake. Quite low temperatures persist

Photo 3.3-1: Water quality sampling in Gregoire Creek at exit from Gregoire Lake.

Photo 3.3-2: Brown coloration of water in Surmont Creek, indicating muskeg origin.

in Surmont Creek and Culvert Creek well past snowmelt and break-up dates. They also persist longer in Surmont Creek than in Culvert Creek. This is quite likely a result of the lower temperature run-off from muskeg regions (Table 3.3-4). (Investigation of muskeg areas near the Stony Mountain Radar Station in late May and early June showed that, while flow from the muskeg was occurring, the muskeg was still ice-bound at depths greater than six inches to a foot (15-30 centimetres).) Surmont Creek and Culvert Creek contributed flow that was cooler than the temperature of the waters of Gregoire Lake until early June. From mid-July into September the flow from these tributaries was somewhat warmer than the waters of Gregoire Lake. Should future investigations of Gregoire Lake show that temperature is a significant factor in the quality of the water, information on this seasonal fluctuation could be put to some use by diversion of water with undesirable thermal properties.

Water quality in Gregoire Lake is generally good for all present uses throughout the year. In spite of the fact that much of the lake is relatively shallow, winter kill does not appear to be a problem. Gregoire Creek discharged from the lake throughout the study year. As previously indicated, flow was observed to decline to as little as ten cfs (0.4 $M^3$/s) in the winter months (perhaps less in extremely dry years). Weed growth is a problem in the shallower areas late in the summer, and while this does not appear to detract from the environment in terms of fisheries production (in fact, quite the contrary), it is not ideal for optimum recreational utilization. Water quality is not consistent throughout the lake, probably

resulting from both the major tributaries and the outlet all being located on the south shore. General observations of the visual characteristics (eg. coloration) near the Gregoire Lake Provincial Park, the park near Anzac, and at various points along the southern shore, indicate that the mixing of the tributary waters is not very thorough. The characteristic brown coloration of the tributaries (Surmont and Culvert Creeks) during and after heavy run-off is also present to a lesser extent in Gregoire Creek. However, this coloration is lacking to a significant extent in the eastern, northern and western portions of the lake. This would indicate a flow pattern within the lake occurring from the south-west (the mouths of the tributaries) eastward along the southern shore and exiting from the lake via Gregoire Creek. This flow pattern may be supported by the dominance of northerly and westerly winds. This incomplete mixing does not seem to have a detrimental effect upon the remainder of the lake.

Temperature in the lake appears to have little areal or vertical variation. A preliminary temperature survey was conducted utilizing a YSA telethermometer and a forty foot extension on September 14, 1975. This was primarily to determine if a more complete survey could be justified. Spot checks throughout the lake indicated less than a 0.5$^{o}$C deviation from a temperature of 17$^{o}$C. In addition, there does not appear to be any significant vertical variation of temperature in the lake, probably owing to the relatively shallow depth. It is apparent that some inversion of temperature exists in the lake during the winter months, followed by seasonal over-turning in the spring.

It is likely that this overturning, in addition to wind-generated turbulence and good penetration of the relatively clear water by sunlight quickly counteract any stratification soon after break-up.

# Chapter IV

# The Water Balance of the Gregoire Lake Area

## 4.1 The Water Balance Equation:

As has been discussed in the preceding chapter, precise relationships between surface run-off and precipitation will be impossible to determine owing to the lack of daily streamflow records in the Gregoire Lake Basin. The record for the nearby Hangingstone River provides some basis for an indirect assessment of conditions in the Gregoire Lake Basin, but much of the information necessary for run-off prediction in the study area must be projected from lake level data, stream guaging undertaken in conjunction with selected storms, and particularly the available meteorological data.

Meteorological data are available from four stations either within the study area or in close proximity to it. These include the Ft. McMurray Airport, Anzac, Stony Mountain LO and Stony Mountain Radar (Figure 4.5-1). These data are applied using Thornthwaite procedures to calculation of a water balance for the areas (Laycock, 1967, 1973). The objective is partly one of determining the duration and intensity of run-off patterns by comparison of observed streamflow characteristics, available hydrographs and calculated soil moisture surpluses. The more general objective is to improve the regional perspectives concerning hydrometric relationships.

A water balance equation has been shown to be an effective device for calculation of a water budget for a drainage basin (Penman, 1963). The relationships and techniques established by Thornthwaite

(Thornthwaite and Mather, 1955), with some modifications suggested for regional conditions (Laycock, 1961, 1967, 1973), have been used in a book-keeping procedure in conjunction with the following water balance equation:

$$Ppt = (PE - D) + S \pm SC.$$

In the above equation, Ppt represents precipitation, PE represents potential evapotranspiration, while D and S indicate deficit and surplus, respectively. SC indicates the change in soil moisture storage levels and snow detention between the beginning and the end of the period under consideration.

The information obtained by the application of this equation to meteorological data via an accounting of conditions in selected soil moisture storage capacity categories in time units of one month will yield yearly surplus and deficit totals for each category. This information can then be applied with a mapping of soil moisture storage categories throughout the study area, resulting in a total surplus figure for the drainage basin. Corrections for retention and detention storage must be considered before a final run-off regime can be determined.

## 4.2 Regional Considerations:

Techniques other than the one chosen for this study could theoretically provide the same results as the Thornthwaite tabulations. For instance, work done by Blaney and Criddle (1950) or Turk (1954, 1955) are based upon the same basic parameters and assumptions as

Thornthwaite. However, the availability of results of similar work elsewhere in the province utilizing the Thornthwaite techniques makes it a clear choice done over the others for the sake of comparison. Work done by Budyko (1956) or Penman (1963) might well provide superior accuracy at higher latitudes owing to their use of radiation measurement in addition to temperature measurement for the calculation of potential evapotranspiration rates. In the case of the present study area, however, radiometric data from a station near enough to the study area to preclude error introduced by local variations in meteorological conditions were unavailable. It would have been necessary to use extrapolated estimates instead of actual data. The use of these estimates with little local supporting data in an equation of empirical derivation would introduce a great potential for error. Therefore, the choice of the Thornthwaite technique seems reasonable.

Measurement of precipitation is relatively straightforward; data from the Ft. McMurray Airport and Anzac stations were essentially unaltered. Some projections of data for the Stony Mountain LO station have been necessary, and are covered in detail below. Evapotranspiration rates at relatively high latitudes are subject to some inaccuracies owing to the greatly increased length of day centered around the summer solstice. Tables provided by Thornthwaite only provide corrections for latitudes of up to 50°. For these and other reasons the figures resulting from the water balance book-keeping procedures should not be interpreted as precise, but as a more general indicator of conditions and trends. None-the-less, there is some precedent for using Thornthwaite

techniques in Alberta under somewhat similar conditions. Work by McIver (1966) in the Spring Creek Basin indicated that run-off predictions can be made with a fair degree of accuracy under conditions similar to those in the Gregoire Lake Basin. Earlier work by Laycock (1957, 1961, 1964, 1967) in the prairie provinces also indicates that water balance equations (with some regional modifications) are useful for this purpose. Stream gauing in future years should establish the degree to which the proposed figures are valid; in this respect, the run-off figures suggested are preliminary.

## 4.3 Climatic Data Acquisition and Adjustment:

Precipitation and temperature data were obtained for the four stations (Section 4-1) within and adjacent to the study area (Environment Canada, 1975). For the study year the most important of these stations is one located in the hamlet of Anzac (Table 4.3-1). Full years of record are available for water balance computations during the years 1951-56, and from 1974 to the present. Since no soil moisture storage levels were calculable for the deeper storage levels in recent years utilizing the Anzac data alone, soil moisture storage levels were adjusted in accordance with the data from the nearby Ft. McMurray Airport station (Table 4.3-2). Although the data from Ft. McMurray and Anzac are similar, the somewhat wetter conditions at the Anzac site would indicate that this correction may yield somewhat conservative estimates of surpluses for the deeper soil

moisture storage categories. Fortunately, 1974 (the year for which water balance calculations based upon the Ft. McMurray Airport soil moisture storage levels were initiated) was a relatively wet year, with significant recharge occurring in the deeper storage levels. Even the modest snowfall of the winter of 1974-1975 was sufficient to bring the deepest storage categories to capacity before any soil moisture utilization occurred. From this point in time the Anzac water balance calculations do not include any adjustments in data or methodology.

The Ft. McMurray Airport station is the only long term station which has been recording throughout the year. In operation since 1949, its records are useful to this study for several reasons. Owing to its location, the Ft. McMurray data are representative of the more general implications regarding the climate of the region. In years where records from other stations are incomplete, this record can serve as a general indicator of conditions. The data in Table 4.3-2 are essentially complete and unaltered.

The Stony Mountain LO station has a reasonably long period of record, commencing in 1954 and continuing to the present. Records are kept through the months of potential fire hazard--usually from May through September. Year-round records were kept for a period of four years at the now-abandoned radar site, located just outside the study area (Figure 4.5-1). (Although the proper designation for this station is "Stony Mountain", it will be referred to as "Stony Mountain Radar" for clarification purposes. During the early periods of record, "Stony

Mountain LO was referred to as "Stony Mountain Forestry"; the former of these designations is used throughout.) Analysis of the data of these two sites for the months of concurrent record shows good agreement with temperature (and thus evapotranspiration) being very similar, while precipitation was greater at Stony Mountain LO by eight per cent. Given the period of record, this is probably not a significant variation, considering the localized nature of summer thunderstorms in the area. Elevation differences between these two stations are negligible. The slightly higher precipitation at the Stony Mountain LO station may be attributed to its closer proximity to the escarpment and consequent greater exposure to orographic uplift influences.

Some indication of climatic patterns throughout the year are valuable for run-off calculations in the upper portion of the Surmont Creek Basin. The Stony Mountain LO adjusted data (Table 4.3-3) represents, then, an estimate of potential evapotranspiration and precipitation for the Stony Mountain Plateau. Probability of error in the projections of potential evapotranspiration are slight, since the only monthly totals of PE which are not a part of the Stony Mountain LO data are October and April. The months before April and after October average below freezing, and thus PE is nil for the purposes of Thornthwaite calculations. Potential evapotranspiration in Anzac for April and October is 0.35 inches (8.9 mm.) and 0.55 inches (14.0 mm.), respectively. In accordance with the average temperature deviation during the period of concurrent record between these two stations, these values have been adjusted to nil for April and 0.28 inches (7.1 mm.) for October.

Precipitation data for Stony Mountain LO have been projected in accordance with the Stony Mountain Radar data (as noted above), taking into account a correction factor for the relative wetness of the years 1959-63 in the Ft. McMurray region. The margin for error is much more significant in these projections than for those of potential evapotranspiration. Owing to the lack of a statistically significant period of record, it should be suggested that the precipitation figures for the Stony Mountain plateau during the winter months are more in the nature of long term average figures adjusted somewhat for orographic effect (see below), and the meteorological peculiarities of the study year. Despite this, they should render a more realistic figure for run-off calculations than if lowland station data were utilized as representative of the entire basin. The adjusted figures for Anzac and Stony Mountain LO are markedly dissimilar. Potential evapotranspiration figures for Anzac are one to two inches (25-50 mm.) higher than those for Stony Mountain LO, while precipitation is roughly sixteen per cent lower. Long term water balance equations for the three stations currently in operation would appear generally as follows:

Table 4.3-4: Long Term Water Balance Equations

| | |
|---|---|
| Ft. McMurray A[1] | 17.23" = 19.20" - 2.73" + .76"<br>(440 mm) (486) (71) (25) |
| Anzac[2] | 21" = 19" - 2" + 4"<br>(533 mm)(483) (51) (101) |
| Stony Mountain LO[2] | 25" = 17" - 1" + 9"<br>(636 mm)(432) (25) (229) |

[1]Long term normal data (Laycock, 1974), presuming a four inch (102 mm.) storage capacity.

[2]Long term normal data are not available for these stations. These equations are estimates to the nearest inch, presuming a four inch (102 mm.) storage capacity (Appendix 2).

It seems likely that the differences in the water balance equations over such relatively short distances are due in large part to orographic influences. The driest of the three sites, Ft. McMurray, is at an altitude of 1211 feet (369 metres); Anzac is at 1580 feet (481 metres), with the change in elevation between the two being gradual and reasonably constant. In contrast, the Stony Mountain LO is on top of the escarpment at an elevation of 2500 feet (762 metres), with Anzac being near the base of this escarpment (Figure 1.2-1). The rise between the two is relatively abrupt, Anzac being less than eight miles (12.8 kilometres) away. The distance between Anzac and the Ft. McMurray Airport station is more nearly fifteen miles (24 kilometres). The very small elevation difference involved between Ft. McMurray and Anzac would account for the slight difference in temperature; a standard vertical lapse rate estimate would be approximately a one degree Farenheit (0.5$^{O}$C.) temperature differential. The same rate computed over the 1000 foot (300 metres) rise from Anzac to the Stony Mountain fire tower would result in a difference of close to three degrees Farenheit (1.7$^{O}$C.). The records do, in fact, bear this out. Consequently, potential evapotranspiration rates for Ft. McMurray and Anzac are similar, but a significant decline in PE rates can be attributed to the elevation of the Stony Mountain Plateau.

There appears to be an important orographic effect on snow-pack accumulation in the Ft. McMurray region as well. This has been supported by observations on Stony Mountain during the study season. Since the greater portion of the Gregoire Basin is subject to orographic

effects, it may well be that the snowfall constituent of the total precipitation is also subject to both increased precipitation rates and reduced evapotranspiration rates.

It was not possible to carry out a snow gauging program throughout the winter of the study year. However, measurements of total snowpack were made prior to significant melting. These measurements were made during the first three days in April, 1975. It is recognized that the results of a single seasons snow-catch are not subject to coherent statistical analysis. This is particularly true of the winter of 1974-75 owing to lighter than normal snow-fall. In spite of these limitations, it appeared that snowpack did tend to increase with elevation (Photos 4.3-1, 4.3-2, Appendix 3).

Landsat imagery of the region was not available during the study year. For this reason, imagery from the previous year was used in analysis of regional snow-pack patterns. MSS bands five and seven recorded on April 15, 1974 were of excellent quality and there was negligible cloud cover. Microdensitometric enhancement of these images is indicative of a positive correlation between altitude and snow-pack (Photo 4.3-3). These areas of greater snowpack are represented by the cooler colors of the spectrum (blue and violet), whereas the areas of lighter snow-cover are represented by the warmer pinks and oranges. (This reversal of tonal assignation occurred as a result of utilization of negative imagery.) The major areas of concentration of these cooler colors can be identified as the Thickwood Hills, Birch Mountain and the margin of Stony Mountain. Thus, heavy snow-pack is indicated on the only regional relief features

Photo 4.3-1: Relatively deep snow near summit of Stony Mountain Escarpment. (9.83" or 24.6 mm)

Photo 4.3-2: Light snowpack along Anzac road. (3.75" or 9.4 mm.)


Photo 4.3-3: Enhanced Landsat imagery of Ft. McMurray area.

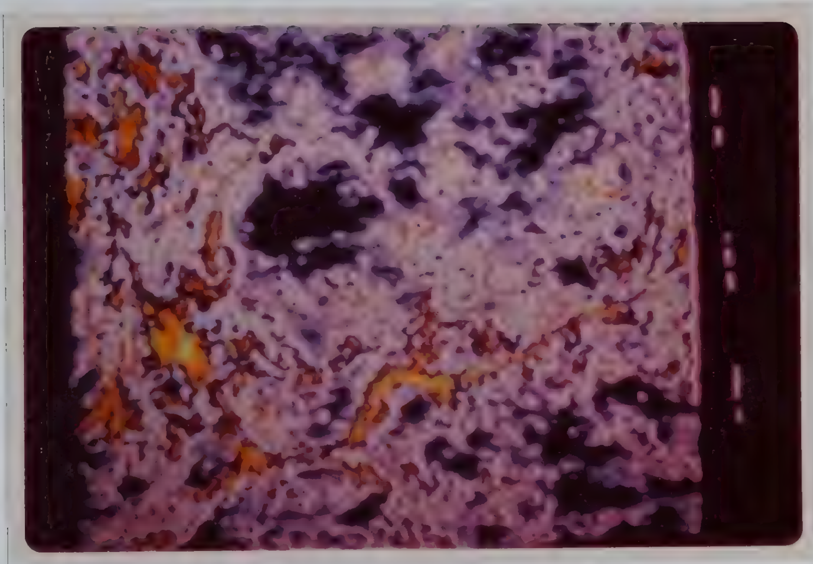


Photo 4.3-3: Enhanced Landsat imagery of Ft. McMurray area.

capable of generating altitudinal climatic variation.

There are several possible causative factors for the observed snow accumulation in the more elevated areas. The combination of orographically induced increase in precipitation and vertical thermal lapse rate is probably the most important of these. Slower melting would indicate not only longer maintenance of the snow-pack in spring, but also earlier commencement of accumulation in the fall. Other factors such as slope, aspect, and vegetation type can also have a significant effect upon melt rates. (These factors also affect imagery interpretation. Since only general trends were desired, no attempt was made to correct for these factors.) Regardless of the causation, added accumulation of snow in upland regions will have a distinct effect upon the water balance of the region. The delayed utilization of snowmelt in soil moisture recharge until the warmer months is likely to result in decreased deficits. More importantly, fully recharged soil moisture storage capacity in the season of heaviest precipitation is likely to increase surpluses. Recharge of even the deeper storage categories is likely to occur in more years, resulting in increased flow from these areas. It is difficult to assess the effect on peak flows, but higher flows are likely to be sustained for longer periods and later into the season than if the slow release of moisture from the melting snowpack was not present.

In general, then, precipitation relationships are not as direct as those of temperature and evapotranspiration. This is perhaps a result of the more modest areal extent of individual thunderstorms, but

more likely a result of the massive orographic uplifts of air masses which are likely to alter precipitation producing conditions aloft. The resulting precipitation is transferred to ground level observation stations, whereas the air temperatures at ground level are less affected.

## 4.4 Local Water Yield Variations:

The run-off characteristics of a basin are directly related to a number of factors one of the more important of which is vegetative cover (Penman, 1963). Several vegetative cover parameters have been shown to be important in their effects upon evapotranspiration rates. Ages of vegetation stands are important, since PE generally increases as a function of increase in total biomass within a single species. Age also results in deeper rooting of the stand, with consequent availability of soil moisture storage from deeper zones during times of soil moisture utilization. Species is also a decisive parameter in determining PE, not only because of the greater biomass per unit area of some species over others, but also the ability of some species to transpire greater volumes of water per unit biomass. This relates partly to albedo of the cover, and partly to leaf structure, in addition to a number of other factors (Penman, 1963). Also important are the apparent differences between species in their ability to contribute substantial transpiration either later or earlier in the season than others. In the Gregoire Lake area, this might be exemplified by spruce

on the one hand, and aspen on the other, since leaf loss by the aspen in fall and late development in spring prevents significant transpiration while the needles of the spruce have this ability.

The storage categories chosen for this study are preliminary and open to modification pending results from future years. In accordance with the above listed factors and with estimates used elsewhere in the province (e.g. Laycock, 1962, 1967, and McIver, 1966), the following assignations were made:

1. 0.5" (12.5 mm.) - cleared areas of bare soil, roads, campsites.
2. 2.0" (51 mm.) - cleared pasture areas, marsh and muskeg. (The dead organic cover in muskeg areas limits losses from evapotranspiration. Wight, 1973)
3. 4.0" (102 mm.) - sparsely treed or brushy muskeg areas.
4. 6.0" (152 mm.) - immature deciduous tree cover, sparsely timbered areas (largely in dead ice moraine).
5. 10.0" (254 mm.) - mature, well established forest cover, generally coniferous, but some mixed deciduous stands.
6. Surface water - calculated with no maximum storage level, with one-half the deficit from the six inch category added to PE in estimating evaporation.

The drainage basin was mapped by the author from air photo imagery of two different scales (Alberta Energy and Natural Resources, 1951, 1967). The northern half of the basin was mapped from 1:31,680 scale photography, which was deemed adequate for the relatively large,

homogenous areas of the above listed categories. The southern portion of the basin was mapped from photography of 1:15,840 scale. Although this detail may not have been entirely necessary, some difficult problems in interpretation were found to exist in the southern half of the basin. Vegetation distinctions in areas covered by more undulating till were unclear; in these areas an average storage level is assigned where practical. These areas also involved some minor problems in definition of drainage divides. In the southern-most margins of the basin the extremely low relief made definition of the drainage divide extremely difficult. Hydrologic features are poorly developed at best, while in some instances there is evidence of shifts in drainage direction or in lake outlets. The margins of the basin in the most difficult cases were finally determined by the flow directions as indicated by the chevron-like appearance of some of the muskeg surfaces.

Final transfer of the photography based patterns to the base map was done at a scale of 1:63,360, utilizing a zoom transfer-scope[1] for some of the more complex areas. Areas for each of the mapped units were calculated utilizing an additive planimeter; original calculations were performed in acres, with final conversions being in square miles and square kilometres. These are recorded both as total areas for the purposes of run-off calculation, and as percentages of the total basin, for comparative purposes (Figure 4.5-1).

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[1] Zoom transfer-scope made available through the Alberta Remote Sensing Centre.

## 4.5 Distribution of Storage Capacity:

The study area was divided into two unequal parts based upon the orographic considerations previously discussed (Section 4.2). The water balance for the southern half of the basin was calculated utilizing the data from the Stony Mountain LO, while that in the northern half was calculated utilizing the Anzac data (Figure 4.5-1).

The lower (northern) portion of the basin has an area of approximately 38.4 square miles (99.7 square kilometres). The most noteworthy feature of the basin is Gregoire Lake, for it constitutes the greater portion of the area mapped as surface water. The area designated as surface water is quite large, covering about 27.3 per cent of the lower basin. The six inch (152 mm.) storage capacity area is not of great importance, having been mapped as only 3.6 per cent of the area. The most extensive of the deeper storage areas in the lower basin is that with a ten inch (254 mm.) storage capacity. 59.0 per cent of the lower basin was designated as having heavy deciduous, coniferous or mixed stands of trees ranging from thirty to sixty feet (ten to twenty metres) in height. This storage category incorporates almost the entire high slope area in the lower basin, in addition to most of the backshore area around Gregoire Lake. The area around Gregoire Lake Provincial Park is dominated by this category.

The lower storage capacities are not strongly represented in the lower basin, totalling only 10.1 per cent of the area. Of this amount, 3.5 per cent is marsh or muskeg (two inch or 50 mm. storage capacity), with low evapotranspiration rates because of the cover of

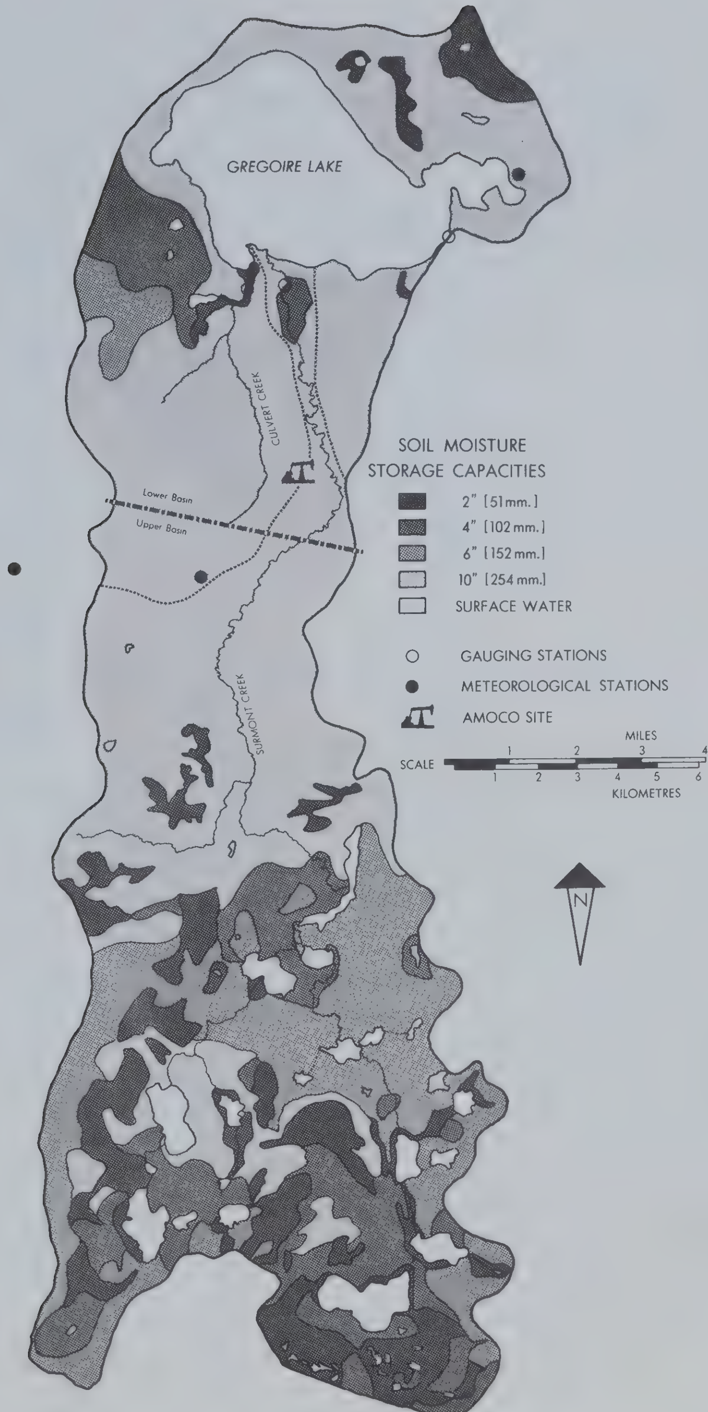



FIGURE 4.5-1 AREAL DISTRIBUTION OF SOIL MOISTURE STORAGE CAPACITY

Table 4.5-1: Distribution of Soil Moisture Storage Capacity

| | Upper Basin Sq. mi. (Km$^2$) | % | Lower Basin Sq. mi. (Km$^2$) | % |
|---|---|---|---|---|
| Water | 4.688<br>(12.141) | 7.1 | 10.464<br>(27.102 | 27.3 |
| 2" | 11.020<br>(28.542 | 16.8 | 1.339<br>(3.468) | 3.5 |
| 4" | 6.931<br>(17.951 | 10.5 | 3.519<br>(6.524) | 6.6 |
| 6" | 16.230<br>(42.036) | 25.3 | 1.389<br>(3.598) | 3.6 |
| 10" | 26.261<br>(68.016) | 40.3 | 22.634<br>(58.622) | 59.0 |
| | 65.129<br>(168.684 | 100% | 38.346<br>(99.316) | 100% |

dead organic material. The remainder is in the four inch (102 mm.) storage category, consisting of either treed muskeg or open meadow used for rough pasture. The one-half inch (12.5 mm.) storage capacity does exist in the lower basin mainly as roads and clearings, partly in the hamlet of Anzac and at the Amoco site; the total area involved does not, at present, constitute a significant factor for the calculation of run-off for the Gregoire Lake basin, and was therefore deleted as a mapping category (Table 4.5-1).

The upper basin (the southern-most portion of the study area) is considerably larger than the lower basin, having an area of approximately 65.1 square miles (168.7 square kilometres). Owing to the location of the greater portion of this area on top of the Stony Mountain Plateau, it is presumed to have the climatic characteristics of the Stony Mountain LO station. The nature of the storage categories in the upper basin is similar to those in the lower basin, but owing to a preponderance of muskeg conditions in the southern-most portion of the upper basin, there is a higher percentage of shallow storage categories.

The deeper storage categories are located nearest to the escarpment. Approximately 40.3 per cent of the area has been assigned a ten inch (254 mm.) soil moisture storage capacity. This is primarily along the better drained edge of the escarpment and in other areas of greater relief in the basin. Vegetation patterns for this category are very much the same as in the lower basin. It is noteworthy that even though the total acreage of this mature forest cover is great,

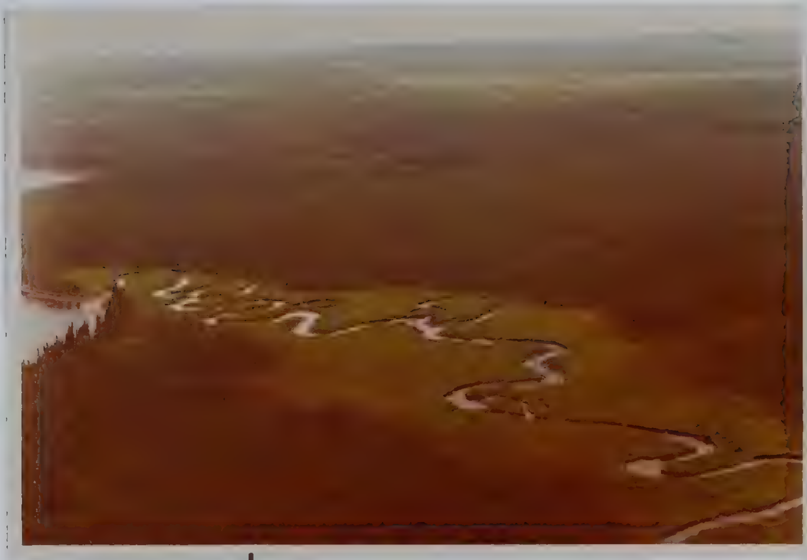


Photo 4.5-1: Surmont Creek entering Surmont Lake. (Photo courtesy Arch Landals)

Photo 4.5-2: Muskeg and treed muskeg south of Surmont Creek. (Photo courtesy Arch Landals)

it is relatively less than the areal proportion of ten inch (254 mm.) storage category found in the lower basin. The areal percentage of the remainder of the deep storage capacities is nearly the same as in the lower basin. 25.3 per cent of the area is designated as having a six inch (152 mm.) storage capacity, being mapped as immature forest or scrub. Another 7.1 per cent constituted the surface water of the upper basin. This is very nearly the reverse of the percentages of water and six inch (152 mm.) storage capacities present in the lower basin. In this particular study year the ratio of land with deeper storage capacity to surface water area did not appear to have a large effect on calculated surplus since there was no deficit in the deeper categories. If the adoption of an altered equation (Section 4.4) for the calculation of surpluses from surface water areas is correct, then less run-off from the surface category should be expected in dry years than from the deep land storage categories. This could be important in the Gregoire Lake Basin, since even by regional standards, the percentage of water surface in the area is high (Table 4.5-1).

The most noteworthy aspect of the distribution of soil moisture storage patterns in the upper basin is the relatively great area in the lower storage capacities. While again there is no significant area mapped as one-half of one inch (12.5 mm.) storage capacity, the two inch (51 mm.) and four inch (102 mm.) categories occupy about 27.3 per cent of the upper basin. Of this amount, 16.0 per cent is categorized as open marsh or muskeg with a storage level of two inches (51 mm.), whereas the remainder is classified as treed or scrubby

muskeg in the four inch (102 mm.) category. This is a significantly larger proportion than exists in the lower basin.

These lower storage categories may be expected to influence the surplus patterns of the study area. The low potential storage capacity would result in high yield even for relatively dry years. This surplus is at least partially a function of reduced evapotranspiration rates from the boggy areas, rather than a lack of storage depth or lower infiltration rates. A slowing of run-off rates may also be anticipated resulting from the high detention storage associated with the extremely low relief and poor drainage evident in the areas with lower storage categories. This tendency is also related to the many small lakes and sloughs associated with the muskeg areas. The combination of high yield and high detention storage may be expected to produce a run-off pattern of sustained high flows rather than the rapid fluctuations between high peaks and deep depressions in the hydrographs normally associated with run-off from areas with the lower storage capacities.

Several important over-all patterns may be noted in the distribution of soil moisture storage categories in the study area. The percentage of the surface area covered by water is unusually high for this region. The percentage of the area in muskeg is not unusual by regional standards, but is important in relation to run-off patterns. The preponderance of this latter category in areas under the influence of orographically induced precipitation suggests the probability of greater yield from this basin than might be expected

elsewhere in the region.

4.6 Surplus Patterns:

As has been noted previously, the study season was wetter than normal. Accordingly, the yield figures calculated using Thornthwaite methods for this year cannot be considered as representative of normal conditions. In spite of this, a reasonably clear indication of major run-off patterns is evident, especially as they relate to the orographic factors and to the lower storage categories.

Calculated yields for the lower basin are within the range of normal patterns estimates for this area. The lower storage categories have relatively high yields; the comparison of surplus figures from the two inch (51 mm.) and four inch (102 mm.) storage categories is indicative of the degree to which potential storage depth is important even in a wet year. While the two inch (51 mm.) category is only about one-half the area of the four inch (102 mm.) category, the run-off from the deeper area is only slightly greater (Table 4.6-1). It is evident from these surplus figures that any major shift in the relative acreages of the shallow categories to the deeper categories in the lower basin could radically alter yield patterns in some years (See Table 5.4-1). During the study year the run-off from the lower basin originated predominantly in the ten inch (254 mm.) storage category and the surface water area. While the yield from these areas was relatively low (2.69 inches or 68.3 mm.), nearly nine-tenths of the

Table 4.6-1: Gregoire Lake Basin Yield - 1975

| Storage Capacity " (mm.) | Area Acres (Hectares) | Yield Inches (mm.) | Surplus afy (hmy) |
|---|---|---|---|
| | UPPER BASIN | | |
| Water | 3000.02 (1214.1) | 12.94 (322) | 3235 (399.0) |
| 2" (51) | 7052.66 (2854.1) | 13.74 (349) | 8075 (996.0) |
| 4" (102) | 4435.65 (1795.1) | 12.94 (327) | 4783 (590.0) |
| 6" (152) | 1038.24 (4203.6) | 12.94 (327) | 11201 (1381.6) |
| 10" (254) | 16807.16 (6801.7) | 12.94 (327) | 18124 (2235.6) |
| Sub Total | 41682.73 (16,868.6) | | 45,418 (5602.3) |
| | LOWER BASIN | | |
| Water | 6696.88 (2710.2) | 2.69 (68) | 1501 (185.2) |
| 2" (51) | 856.73 (346.7) | 5.63 (143) | 402 (49.6) |
| 4" (102) | 1612.20 (652.4) | 3.63 (92) | 488 (60.2) |
| 6" (152) | 888.83 359.7 | 2.69 (68) | 199 (24.5) |
| 10" (254) | 14486.59 (5862.6) | 2.69 (68) | 3247 (400.5) |
| Subtotal | 24541.23 (9931.6) | | 5837 720.0) |
| BASIN TOTAL | 66223.96 | | 51255 (6322.9) |

lower basin has these storage categories. As indicated in the water balance tables for Anzac for 1975, there was a surplus from even the deepest storage categories during at least four months of the year (Appendix 4). Storage capacities were nearly exceeded again during September. A daily calculation would indicate greater surpluses for August, and indeed for most of the summer, as several of the storms were sufficiently close to each other that evapotranspiration between them did not deplete soil moisture storage levels significantly and surpluses would have been registered (see Figure 3.2-1).

The greater part of surface flow in the Gregoire Lake Basin originates in the upper two-thirds of the basin. During no month was there a deficit in any storage category. All months and all storage categories were represented in total yearly surplus figures. Even during June, the driest month of the 1975 run-off season, storage capacity in all categories was exceeded by 0.44 inches (11.2 mm.). As a result of the high total precipitation during the study season, yields from all storage category areas were high, with figures from the shallowest storage capacity being less than one inch greater than those from the deepest storage capacity. It is again the case that the greater part of the calculated run-off originates in areas having deeper storage capacity due to the greater areas involved (Figure 4.5-1), but in the upper basin the muskeg areas make a somewhat greater relative contribution to the total run-off. This tendency would be much more apparent in a dry year, when the deeper categories would not contribute greatly to surpluses (Appendix 4).

The relative wetness of the study year was not sufficient to disguise yield differentiation patterns resulting from depth of soil moisture storage capacity in the lower basin. In contrast, the orographic precipitation in the upper basin reached proportions during 1975 that do not allow calculations to be indicative of probable longer term surplus patterns. Nearly constant yield is indicated from all storage categories. In average and drier years this will not be the case, since the shallower capacity areas will have soil moisture deficits after storage has been depleted. After these shallow capcities have been recharged during a rainy spell, surpluses may be experienced. In contrast, in the deeper categories withdrawal from soil moisture storage may continue throughout a dry year. Consequently, precipitation will have a deeper recharge requirement before capacity is reached. This capacity was full for all months in 1975, with consequently little differentiation between shallow and deep storage categories in terms of their contribution to surplus. Consequently, the areas of muskeg and treed muskeg will contribute relatively more to the total run-off in years of average or less precipitation.

The Hangingstone River hydrograph was used as a basis for comparison with flow conditions in the Gregoire Lake Basin. Yield per unit from the Gregoire Lake Basin was probably somewhat greater than that from the Hangingstone River Basin because of the larger relative area at higher elevation. Yield calculated from approximated flow figures based upon period guaging undertaken on Gregoire Creek at

Table 4.6-2: Relative Yield and Discharge

| Name | Drainage Area | Mean Discharge | Yield |
|---|---|---|---|
| Gregoire Creek | 103.5 $mi^2$ | | Yield |
| Gauge estimate | (268.1 $km^2$) | 60 cfs (1.70 $M^3/s$) | 7.87" (199.9mm.) |
| Thornthwaite | | 71 cfs (2.01 $M^3/s$) | 9.29" (236.0 mm.) |
| Hangingstone River | | | |
| Hydrograph | 344 $mi^2$ (891.0 $km^2$) | 188 cfs (5.32 $M^3/s$) | 7.42" (188.5 mm.) |

the outlet from Gregoire Lake is slightly in excess of that recorded for the Hangingstone River (Table 4.6-2). Yield for the Gregoire Lake Basin based upon calculations utilizing Thornthwaite techniques may be somewhat higher than the estimates based upon field guaging. Both of these figures are within a reasonable range of error relative to what might be anticipated, in spite of the different basin characteristics of the Hangingstone River and Gregoire Lake.

## 4.7 Over-all Patterns:

The relationship of soil moisture storage to run-off patterns has been previously discussed. It has been noted that yield from muskeg areas is high as a result of low potential evapotranspiration rates. The rapidity of run-off normally associated with shallow storage areas is not present. On the contrary, muskeg areas have significant surface detention storage capacities and this in part explains the subdued storm peaking of the streams in the lower Gregoire Lake Basin relative to those shown in the hydrograph of the Hangingstone River. This would contrast with the situation in other low storage capacity areas (e.g. the cut-over forest that would be associated with in-situ development), where high yield is normally associated with rapid run-off. In the upper Surmont Creek drainage, the reservoir capacity of the numerous small lakes also contributes to the maintainence of even flow characteristics. Although it was not the case in 1975, the heavily forested areas of the upper basin will generally be areas of lower yield than the muskeg areas (Section 4.6). The

relatively large muskeg area in the southern-most portion of the basin is likely to be the single most important factor in the maintaining of flow in Surmont Creek during relatively dry years because of this combination of high yield and relatively high detention storage capacity.

# Chapter V

# Water Resources Problems of Oilsands Development in the Gregoire Lake Area

## 5.1 General Hazards:

Gregoire Lake is a viable natural resource utilized heavily by the people of the Ft. McMurray area. Given the nature of in-situ oilsands development, there is a very real danger to the maintenance of this resource in a state which would allow for the continuance of the present range of uses. Present damage is minimal owing both to the small size of the current development and to precautions and corrective measures taken by Amoco. In the future, development will be at a much larger scale. It appears likely that significant problems will occur if this area is developed as planned. Based upon problems encountered in the experimental development, the most severe of these problems will be those related to double-ended hazard of erosion and sedimentation. It is also probable that the alteration in both flow and regime and total yield which would accompany the removal of vegetation would produce unwanted results. Alteration of flow regime resulting in higher and more frequent peaks of flow will also increase susceptibility to erosion. It appears that the problem of erosion on the high slope areas of the Stony Mountain Escarpment may well prove insoluble at reasonable cost, given the anticipated scale and sequence of development. The problems related to alteration of run-off patterns have not yet been perceived by the developers. (See Chapter VI).

Photo 5.1-1: Amoco Gregoire Lake Experimental Site (looking north). (Photo courtesy Arch Landals)

Photo 5.1-2: Vegetation buffer zones remaining between drilling pads at Amoco Site. (Photo courtesy Arch Landals)

## 5.2 Erosion and Sedimentation:

The current Amoco Gregoire Lake Experimental Site has been cleared of vegetation over an area not exceeding fifty acres (20 hectares). Owing to the slope of the Stony Mountain Escarpment at the site it has been necessary to conduct fairly extensive cut and fill operations to flatten the slope to a manageable degree. Precautions taken to prevent erosion to the present have consisted of filling ditches and gullies with dead-falls, brush and logs (Photo 5.2-1). Some attempts at experimentation with revegetation have taken place, but with mixed success (Photo 5.2-2). These measures have for the most part controlled environmental hazards associated with the water resource at the present site. It should be noted, however, that the process water involved in the stimulation and recovery of the oilsands is both supplied by and disposed of in deep wells, and so does not enter into the surface water balance for the basin. This may not be the case at a commercial scale (Chapter VI).

An examination of the erosion and sedimentation which has taken place at the current site is instructive as to the potential for erosion and transportation of sediment which might occur on a commercial scale. Erosion at the Amoco site is primarily limited to the filled areas on the north-east margin of the lease (Photo 5.2-1). The fill utilized is from elsewhere on the lease, and it consists mostly of glacial till, with some organic material intermixed. This till is very unstable, due partially to the constituents of the till itself, partially to

Photo 5.2-1: Brushing and dead-falls as erosion inhibitors at Amoco site.

Photo 5.2-2: Growth of natural grasses on cleared area.

Photo 5.2-3: Sediment leaving lease.

Photo 5.2-4: Fine and medium sand, approximately 200 yards (200 metres) from origin.

the steep slopes involved, and partially to the early season moisture content of the fill. The moisture content appears to be a major factor not only in erosion, but also in mass movement, due to much of the earth moving being done in the winter months. During this period it is not possible to discriminate between snow, ice and earth in fill operations. The melting of the frozen water content of the unconsolidated fill during the spring creates an extremely unstable mass of material. Some mass movement by gravity is involved initially, followed by extreme susceptibility to erosion. This instability makes preventative work very difficult, partly because erosion is likely to begin before the growing season will allow protective vegetative cover to develop.

The transport of sediment from the Amoco site subsequent to erosion would certainly have reached greater proportions if the present precautions had not been taken. In spite of the precautions, a considerable amount of sediment has been transported from the site in the direction of Surmont Creek (Photo 5.2-3). Observations during heavy run-off during summer thunderstorms have made it clear that the material is moved primarily by bed transport processes, as it consists mainly of medium and fine sands (Photo 5.2-4). Transport of these sands has proceded several hundred yards (several hundred metres) from the site. The coarsest constituents of the till have not migrated to the same extent. The clay component of the till is generally not in evidence past the boundaries of the site and may be presumed to have been carried in suspension into the watercourses. (Some thin films

of clay can in fact be found deposited on leaves and other forest litter along high water marks.)

Exploitation of in-situ oilsands reserves on a commercial scale will involve the clearance of up to ninety per cent of the vegetation over an area of about three square miles (7.77 square kilometres) (Amoco, 1973) (Photo 5.1-1 and 5.1-2). Much of the area encompassed by the Amoco leases is on the face of Stony Mountain. The potential for erosion on this amount of bare ground is extreme. It is a high slope area subject to fairly rapid flow, as is indicated by erosion along the forestry roads on the face of the mountain. Although current planning allows for a buffer zone of natural vegetation between each well site, it is unlikely that this will be sufficient to prevent the migration of sediment, especially during the first season after clearance. The Amoco site is not located in the zone of highest slope on Stony Mountain; on the contrary, it is situated near the base of the mountain. The higher slope (and higher precipitation) of the upper escarpment will contribute to even greater potential erosion rates. Although it should be noted that the development sequence of the entire lease area will be spaced over many years, the effects of erosion and sedimentation on Gregoire Lake will be to a great extent cumulative over and even past the period of development.

The danger of sedimentation at present is confined to the Surmont Creek drainage, since most of the erosion from the Amoco site is within that drainage. The gradient of Surmont Creek appears to be sufficient to transport the fine sediment (up to medium grained sand in size)

present in the Stony Mountain Till into Gregoire Lake. Sedimentation resulting from development of those portions of the lease drained by Culvert Creek is not likely to be a hazard to Gregoire Lake. Owing to a lower gradient and poorer channel development in the upper portion of the stream, Culvert Creek does not have the carrying capacity of Surmont Creek. In addition, the presence of the small lake between the high slope area and Gregoire Lake should allow most of the sediment to settle out of Culvert Creek prior to entrance into Gregoire Lake. This area of muskeg and the small lake acts as a sediment trap for virtually all of the Culvert Creek drainage, but the upper portion of Culvert Creek and the small lake itself are subject to sedimentation. (The effectiveness of this lake in lowering sediment loads may presently be observed in the low sediment content of the water samples from Culvert Creek in Table 3.3-3).

There is some potential for alteration of present drainage patterns to take advantage of this natural sediment trap. Water from Surmont Creek could be diverted into the Culvert Creek drainage above the small lake. Alternatively, water from the development area could be channeled into the Culvert Creek drainage before it reaches Surmont Creek. This would involve considerable expense and additional disturbance of the surface. In addition, should Surmont Creek be diverted, some sacrifice of its current use potential would be involved. (Surmont Creek is presently rated as having a moderately good potential for fishing, in this case for grayling. It does not appear to be important in the life cycle of either northern pike or walleye pike, the major

sport fish species in Gregoire Lake.)

It is evident that, of the several factors involved in the erosion and sedimentation problems in the Gregoire Lake area, the most critical is high slope. Previous experience in oilfield and road development in the Swan Hills-Judy Creek area of north-central Alberta is indicative of what may be anticipated in upland areas (Zarachuck, 1974). The situation in the Swan Hills is very similar to that on Stony Mountain regarding high precipitation, high slope, poorly developed soils on glacial till, and general vegetation patterns. Extreme difficulty was encountered in stabilizing steeper slopes (defined as greater than a four-to-one gradient) in the Swan Hills (Lengellé, 1973). Many of the techniques utilized in the Swan Hills area may be applicable to the Gregoire Lake area. It should be noted that corrective work attempted in the Swan Hills was both expensive and only marginally successful, whereas preventative work was less expensive and generally more effective. The importance of integration of reclamation plans with development plans appears to be of the utmost importance both in terms of unit cost and in terms of long range success (Dingle, 1973).

## 5.3 Altered Surplus Patterns and Erosion:

It is evident that, in spite of the minimal size of the erosion and sedimentation problem at present, the problem will be severe if present surplus patterns prevail over a large cleared area. These problems may in fact become more dangerous owing to alteration of surplus patterns. Total yield will increase (Section 5.4), but more

importantly, the timing of this yield will be radically altered. Clearing of vegetation and preparation of the drilling pads will substantially lower storage capacity in the area of development. Infiltration rates are likely to be very low owing to the high clay content of the soil and to the compaction of the soil by heavy machinery in many areas. The effects of these reduced infiltration rates are likely to include initiation of run-off prior to recharge of the shallower storage capacities. (This factor is not taken into consideration when computing the theoretical surpluses in Table 5.3-1.) Run-off in these areas will be very rapid. For this reason, isolated but intense storms in even very dry summers can have a substantial input to surface flow.

Storms during wet years, or early in the summer before depletion of soil moisture storage, will result in even more substantial run-off. Early season storms will also have a minimum of storage to recharge before erosion can begin. These tendencies will be intensified by the clearance of the larger area needed for commercial scale development. Erosion at this scale is not, therefore, dependent upon extremely wet conditions alone, but also upon storm intensity. Minimization of the area cleared around each drilling pad, and consequently of movement of the amount of easily erodable fill necessary, would alleviate the problem somewhat. Directional drilling of multiple wells from a single pad would minimize the number of pads and therefore the total clearance per unit area. Development as planned will result in very rapid run-off and consequently severe erosion problems will be experienced

on high slope areas.

Much of the area under lease to Amoco (and other companies) in the Gregoire Lake area is located on land with relatively little relief. Often this level land is poorly drained, being either muskeg or marshy in nature. Development of these areas is not likely to initiate a substantial on site erosion problem. There is some potential for headward gully erosion where drainage ditches intercept incised stream channels. (e.g. Surmont Creek where incised into the escarpment.) Drop structures or other protective measures may be necessary to guard against this at some locations. Storage capacity and infiltration rates will still be diminished by clearance of vegetation and compaction by machinery, but drainage is more likely to be the major problem (Photo 5.3-1). Some safeguards will certainly be needed; those presently proposed by Amoco are likely to be sufficient to prevent erosion in those areas either above or below the Stony Mountain Escarpment.

## 5.4 Altered Yield Patterns:

While it is difficult to affix a quantitative estimate to increases in sedimentation problems, it is possible to suggest some reasonable estimates of the increase in yield potential which would occur if a commercial scale development was to take place in the Gregoire Lake Basin. Depending upon the storage capacity of the cleared area, an increase in total yield of fifteen to twenty per cent might be expected in a wet year (Table 5.4-1). Figures for a dry year would be

Table 5.4-1: Theoretical Yield Change Resulting from Commercial In-Situ Development[1]

| Storage Levels | Area in Basin $Mi^2$ ($Km^2$) | Yield " (mm.) | Run-Off afy (hmy) | Altered Area $Mi^2$ ($Km^2$) | Run-Off afy (hmy) |
|---|---|---|---|---|---|
| 2" (50.8 mm.) | 13.25 (34.32) | 5.6 (142) | 3962 (488.71) | 38.25 (99.07) | 11,422 (1408.89) |
| 4" (101.6) | 15.25 (39.50) | 3.6 (91.4) | 2942 (362.89) | 15.25 (39.50) | 2942 (362.89) |
| 6" (152.4) | 38 (98.42) | 2.7 (68.6) | 5467 (674.35) | 13 (33.67) | 1871 (230.78) |
| 10" (254.0) | 6.5 (16.84) | 2.7 (68.6) | 2374 (292.83) | 16.5 (42.74) | 2374 (292.83) |
| Water Surface | 17 (44.03) | 7.1 (180.3) | 6454 (796.09) | 17 (44.03) | 6454 (796.09) |
| TOTAL | 100 (259.00) | | 21,199 (2614.68) | 100 (259.00) | 25,063 (3091.51) |

[1]Calculations are based on Thornthwaite procedures for Anzac in 1975. Basin area has been altered from 103.5 $mi^2$ to 100 $mi^2$. English figures in columns two and five are both square miles and percentage. Altered area presumes a change of 25% of the basin from 6" to 2" storage category. "hmy" represents "hectare-metres per year".

higher as a percentage of the total yield, but the actual quantity of water involved would be less. The fact that this greater actual increase in yield would occur in years of already high run-off will increase any problems that might be created.

Total yield changes will undoubtedly have some effect upon the hydrology of the basin, but the alteration of the storage patterns will have a more important influence on the timing of run-off. Streamflow generated as a result of storms in the summer months will be much more rapid. Total surplus for more severe storms will be greater, leading to higher peak flows in Surmont Creek and Culvert Creek. Many sections of the banks of Surmont Creek are susceptible to undercutting and this would be accentuated by more rapid run-off (Photo 5.4-1). Some scouring of the stream bed can also be anticipated, with consequent damage to bottom life. Flooding of the meadow areas in the lower reaches of the stream could also occur with greater frequency and damage if higher and more frequent peak flows are experienced.

Groundwater patterns as they relate to flow in Surmont Creek have not been established, but alteration of the soil moisture storage patterns will affect seasonal flow. Some lessening of detention storage will accompany the shift to the shallower storage capacities, this in turn lessening the contribution of shallow groundwater flow to stream discharge in the dryer months. Infiltration rates will also be decreased, with the same effect. (In addition to stripping of vegetation, compaction by heavy machinery could be a major cause of decreased infiltration rates.) Some increase in stream temperature later in the

season may also be expected (Sharpe, 1975). However, given the relatively high temperatures of the streams flowing into Gregoire Lake late in the season at present, it is unlikely that this will have a substantial deleterious effect as long as vegetation along the streams is retained.

Alteration of the muskeg environment on top of Stony Mountain is unlikely to have a major immediate effect upon run-off patterns in Surmont Creek. The change in soil moisture storage capacity should not be significant, since both the present muskeg environment and a drier cleared environment would be in the lower storage range. An increase in the rapidity of run-off could be anticipated as a reaction to the loss of the detention storage capacity exhibited by the muskeg. In this particular basin, though, the many small lakes in the hydrologic system also provide a detention storage function and they are likely to suppress extreme fluctuations in flow.

Longer term flow changes could well be more significant. If development on the plateau calls for extensive draining of the wetter areas, in several decades the growth of a maturing forest cover will be seen. This will alter present storage patterns in a manner that will lessen present yields by at least several inches each year (Hornbeck, 1975). Alteration of this muskeg environment might well be advantageous for many uses, but in the case of watershed yield, it could be harmful when the vegetation again approaches a climax state. Since the vast majority of flow into Gregoire Lake comes from this portion of the basin, it is essential that even the very long term implications concerning maintainence of this flow be considered.

5.5 Previous Research:

It is unfortunate that the water resource discussion was so incomplete in the environmental impact statement prepared for Amoco. Emphasis is generally upon Culvert Creek (called "Forestry Road Stream") and the potential hazards to Gregoire Creek, generally ignoring the impact upon Surmont Creek and Gregoire Lake itself. Since Gregoire Lake is quite clearly the most important renewable resource in the lease area, a fuller treatment could have been attempted. The importance of seasonal patterns has not been adequately investigated. As has been shown in earlier chapters, seasonal variation can be important, as well as shorter term fluctuations. (For instance, no seasonal hydrograph was attempted; water quality parameters were tested on one date only.) Reference to occasional "thermal effluent" (ibid., p. 102) is not relevant. It is suggested that this might be a danger during months of thermal stratification in Gregoire Lake. In fact, a seasonal investigation would have shown that during those months Surmont Creek is totally frozen and unless a large and sustained flow of heated effluent were released, little flow would reach Gregoire Lake. Other seasonal variations related to water quality were not treated.

Attention is paid to the problem of erosion and sedimentation, particularly to the efforts in reclamation and revegetation. In this respect the study is more complete. The trial plots maintained on site for testing of different species in revegetation did not appear to be flourishing during the test season. Presumably better seed and fertilizer mixes will be developed, with past work done by GCOS and

Syncrude being likely guidelines. Undue importance is attached to erosion and sedimentation along Culvert Creek. As indicated earlier, this stream presents no particular danger to Gregoire Lake due to the presence of the small lake and marshy area at its lower end. Culvert Creek itself is of little significance as a resource since it appears to be intermittent along much of its course. It is, however, a good example of the type of erosion and sedimentation problems which may be encountered when development in the area proceeds.

The considerable impact of the clearing of vegetation on flow regime has not been investigated in even a peripheral manner. As has been discussed above, this is one of the major impacts on the watershed which can be evaluated in other than a purely qualitative manner. Some estimates are made regarding theoretical maximum stage for the various channels, but these are based upon channel hydraulics of present conditions. Certainly alteration of surplus patterns will lead to conditions which will be very different from those of the past. In fact, some of the upper limits assumed in making these estimates (such as stage not exceeding the height of present bridges or culverts) were in fact surpassed during 1975. An adequate assessment of the impact of alteration upon the watershed of Gregoire Lake should have given at least some perspective of the importance of these factors.

# Chapter VI

## Oilsands Development in Other Areas

## 6.1 The Alberta Oilsands Areas:

The total reserves encompassed within the province of Alberta have been generally described (Chapter I). The areas of the Athabasca Oilsands and the associated Wabasca deposits have been more closely described. However, the other major deposits of oilsands with significant reserves are rapidly becoming the focus of greater in-situ development activity, and because of this, require attention (Oilweek, March 15, 1976).

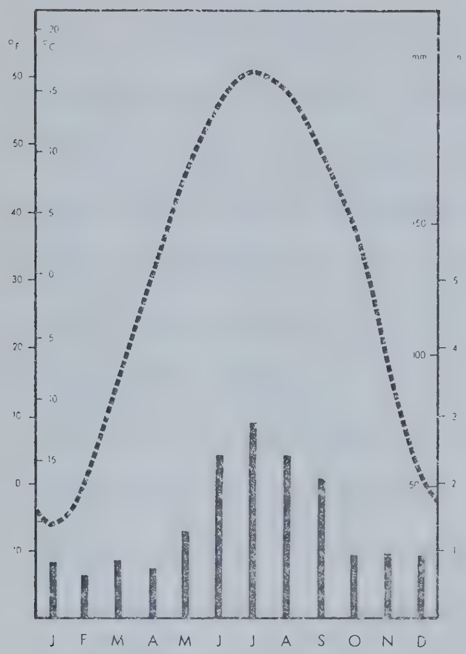
Second in size to the Athabasca deposits are the Cold Lake Oilsands, with estimated reserves of 164 billion barrels (Alberta Mines and Minerals, 1974). The most important development in the Cold Lake region is the program of in-situ experimentation which has been conducted by Imperial Oil since 1964. Current operations at Leming Lake have a maximum production capacity of 4,000 BPD (barrels per day), although average production rates are considerably less. Pilot operations for plants on leases owned by Gulf Oil Co. and Canadian Industrial Gas and Oil, Limited (CIGOL) are anticipated in the same general area by mid-1977. Although the Cold Lake deposits are less extensive than the Athabasca deposits, in-situ techniques are being pursued more actively in the Cold Lake region because of the greater depth of overburden and other geologic considerations (Imperial Oil Review, March 15, 1976; Nodwell, 1976).

Smaller that either the Athabasca or Cold Lake reserves, the Peace River Oilsands are located mainly to the east of the town of Peace River. These deposits are relatively undeveloped, although some permits have been issued for experimental in-situ sites. The only active research in the area has been carried out by Shell Canada; the current status of these operations has been described as "in mothballs", however, and no application for renewal of the recently expired permit has been made (Oilweek, March 15, 1976). As indicated by the disposition of experimental and pilot plant permits, in-situ techniques appear to be the most promising technology for both the Cold Lake and the Peace River regions (Dunbar, 1976).

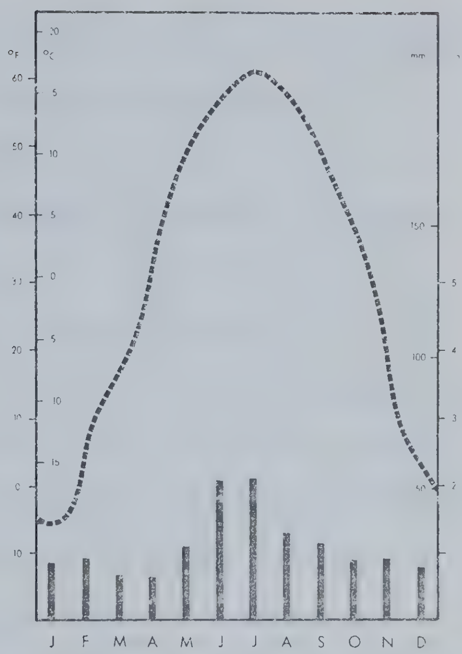
## 6.2 Physical Patterns and Land Use:

It is impossible to closely define a common physical setting for all three areas, although in many aspects they are similar. The Athabasca region has been described (Chapter II). The Cold Lake and Peace River regions have a somewhat less severe climate than the Athabasca region (Figure 6.2-1). The water balance situation is therefor somewhat different in terms of both surplus and deficit patterns. In particular, highland portions of the Athabasca region contribute more heavily to the surface run-off (Section 4.6). Temperatures are somewhat lower, especially in winter, in the Athabasca region, probably a reflection of its somewhat more northerly latitude. The Peace River and Cold Lake regions have longer frost-free periods (Longley, 1968).

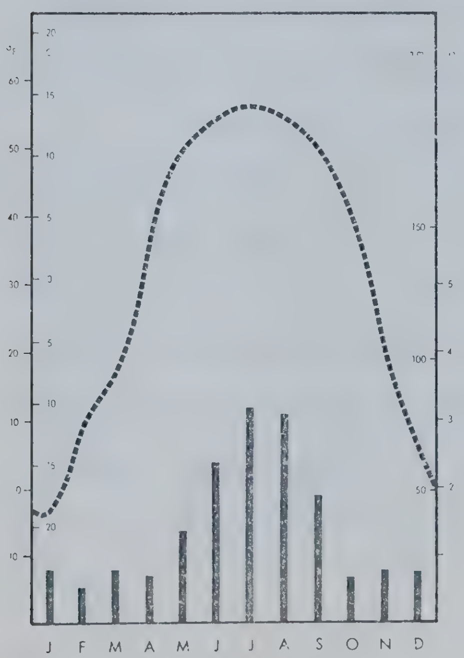
FT. MCMURRAY




PEACE RIVER




IRON RIVER




LONG TERM WATER BALANCE EQUATIONS

| | | |
|---|---|---|
| FT. MCMURRAY | 18 = 19 − 2 + 1 | (inches) |
| | 457 = 482 − 50 + 25 | (mm) |
| PEACE RIVER | 17 = 19 − 3 + 1 | .. |
| | 431 = 482 − 76 + 25 | |
| IRON RIVER | 16 = 20 − 5 + 1 | .. |
| | 406 = 508 − 127 + 25 | |
| STONY MOUNTAIN | 25 = 17 − 1 + 9 | .. |
| | 635 = 432 − 25 + 228 | |

FIGURE 6.2-1 : CLIMATE IN THE OILSANDS AREAS.

Climatic effects upon soils and vegetation are also important considerations in current land use in the oilsands regions. The Athabasca region, as indicated previously, is located in the zone of mixed boreal forest, underlain by grey wooded and organic soils and muskeg is widespread. The Peace River and Cold Lake regions are on the southern margin of this zone and soils tend to be more of the dark grey wooded sub-group. The resulting present and potential agricultural use in the more southerly regions is less limited by climatic and soil deficiencies and cereal grains are successful in most years. Utilization of that land not suitable for grains is limited mainly to forage crops and pasture. There is some potential for forestry, primarily for pulp purposes. Outdoor recreation, especially for water based activities, is of some importance in the Cold Lake region relating in part to the large number of lakes in the region. Current planning indicates that several new provincial parks will come into existence in the area between Cold Lake and Lac La Biche (Landals, 1976).

In contrast, the Athabasca region has a very limited potential for the development of non-renewable resources. No significant potential for the development of agriculture exists and the potential for forestry, recreation and wildlife production are not great (Chapter II). Aside from the exploitation of the oilsands and related service development, the traditional hunting and fishing carried on by the native people are the major current uses of the land. It should be noted that much of the land is unsuited for even this extensive use (Environment Alberta, 1973).

It is evident that land use conflicts in the Athabasca region will be of a very limited nature owing to the scarcity of viable land use alternatives. Conflicts which do occur are likely to be of a site-specific nature, such as the situation in the Gregoire Lake area. More consequential concerns are likely to be the prevention of contamination in the more mobile aspects of the environment, air and especially water. The possibility of these becoming a hazard outside the sites of development must be avoided. Given the scale of the developments and the relatively small areas of value with the Athabasca region, it should prove possible to plan for the accommodation of these concerns.

The variety of present and potential land uses in the Peace River region and particularly in the Cold Lake region makes the potential for land use conflicts somewhat greater. The recent focusing of attention upon the development of in-situ reserves in the Cold Lake region is bringing about a situation where these potential conflicts are becoming more immediate in nature. A mapping of potential conflicts between oilsands development and other land uses at an early date is desirable, but beyond the scope of this study. However, it is possible to suggest topics of concern for watershed management derived from some of the problems encountered in present and past in-situ projects in the Cold Lake and Athabasca oilsands regions. Furthermore, some valuable solutions to specific problems have been determined, and these should be useful in alleviating similar problems in locales outside the site of their original application.

## 6.3 Specific Problems:

The problems encountered in the exploitation of the several oilsands deposits are best defined at this early stage of development by citing specific examples, along with the solutions. In some instances the implications of an absence of a viable solution are explored. Three pilot sites are involved in on-going research, in addition to several other moderately active sites and sites under construction (Figure 1.1-2). Each of these has particular environmental characteristics which set it apart from others, making certain adjustments in development and planning necessary. The Imperial Cold Lake pilot plants are the most active in the Cold Lake region; examples from these closely associated plants are used in conjunction with some information from planning for a Gulf Oil pilot plant expected to be operational by early 1977 (Gulf, 1974, 1976). The lowland setting of the Texex in-situ site near the Ft. McMurray airport is representative of much of the area underlain by the Athabasca deposits, and so reflects some of the problems to be expected as development proceeds elsewhere in that region. The Amoco Gregoire Lake site has some of the problems likely to be encountered in highland areas attributable to climatic and geomorphic factors. In spite of the differences in locale, development and technology, some of the problems are very similar. The solutions to these problems in one area might very well be used to advantage in others.

Potential water resources problems related to commercial scale

in-situ oilsands development can be divided into three broad categories. The first of these is the internal water balance, consisting of the problems of water supply and disposal related to the basic process technology required for the extraction of the heavy soil. Related to this is a second category encompassing the disruption to the environment associated with the preparation and operation of the actual well sites. Finally, problems in the reclamation process and the post-reclamation environment are likely to be encountered on a larger scale operations proceed into commercial production.

A brief description of the technology involved in in-situ recovery is helpful in gaining insight into the internal water balances of the processes. There are several possible methods of in-situ stimulation of the high viscosity oil involved (Figure 6.3-1). All involve the reduction of oil viscosity, at present through the use of heat. Two of these methods, the steam and the combustion techniques, are currently being tested in the field. Two different process variations are also in use in conjunction with these techniques.

Imperial Oil Co. has been conducting experiments since 1964 at its in-situ pilot plants near Cold Lake, Alberta. The steam injection technique is utilized in conjunction with the cyclic stimulation or "huff and puff" method of recovering the oil. Well spacing is variable, with production spacing of five acres (two hectares) or less presently under experimental study. As many as fourteen wells are directionally drilled from a single pad one to two acres (about one-half of one hectare) in size to achieve this density. Steam

FIGURE 6.3-1

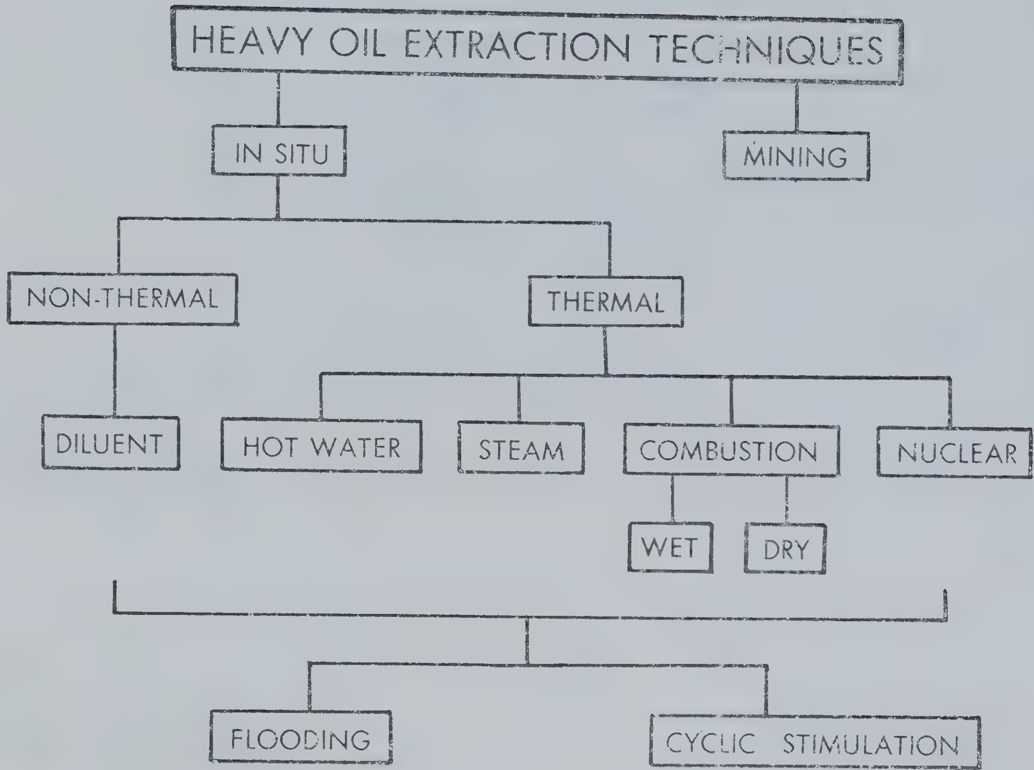

HEAVY OIL EXTRACTION TECHNIQUES
IN SITU
MINING
NON-THERMAL
THERMAL
DILUENT
HOT WATER
STEAM
COMBUSTION
NUCLEAR
WET
DRY
FLOODING
CYCLIC STIMULATION

Table 6.3-1: Internal Water Balance

| Technology | Recovery | Ratio Water:Oil | Process Water Requirements | Quality Parameters | Recycle Potential | Retreatment and Make-up Capacity |
|---|---|---|---|---|---|---|
| Mining Hot Water Extraction | 65% | 6:1 | 37.8 cfs* (1.07 $M^3/s$)** | Less than 3% Solids | 33% | ------------- |
| Steam Injection 'Huff and Puff' | 10-30% | 4:1 | 26 cfs (0.74$M^3/s$) | Total Treatment Strip $O_2$, Ca, Mg, Fe | 90% | 23.4 cfs + (0.66) 2.5 cfs (make-up)(0.07) |
| COFCAW Flood | 50% | 5:1 | 32.5 cfs (0.92$M^3/s$) | None | 90% | 3.2 cfs (make-up) (0.09) |

*cfs - cubic feet per second.

**$M^3/s$ - cubic metres per second.

injection then takes place; the recovery ratio of steam to oil is four to one (Table 6.3-1). Approximately sixty per cent of this water is returned to the surface. A recycle potential of eighty per cent for this returned water has been suggested, although in the current experimental phase two disposal wells are used for the re-injection of waste water. Intensive treatment of the process water is required before it is suitable for use in the steam generators; the water must be totally stripped of oxygen and softened to retard the formation of precipitates in the generator. Water is currently supplied from nearby small lakes and does not exceed 20,000 barrels[1] per day at peak use.

The Texex (Texaco) experimental site near the Ft. McMurray airport is a more recent development utilizing the same basic techniques as the Imperial plant. Water supply for this site comes from Saline Creek, with storage provided in a small reservoir. Current use rates average about 2,000 barrels of water per day. The same water quality stipulations apply as at the Cold Lake development. Precipitates of calcium, magnesium and iron are particularly troublesome. This suggests the advantages of using the natural surface water supply (having lower levels of dissolved solids) over ground water supplies. Snowmelt run-off would be particularly useful in this respect, whereas local groundwater is more likely to be high in solutes. This is particularly true in the Athabasca region (Ozoray, 1974). Surface supplies originating in areas of high organic content (muskeg) with consequently

[1]One barrel is equal to 35 Imperial Gallons or 0.16 cubic metres.

higher iron content are also to be avoided.

The water supply situation at Amoco's Gregoire Lake site is quite different from that at either the Texex or Imperial sites. A partial combustion process--COFCAW[1]--is utilized as the active agent in a flooding recovery operation (Figure 6.3-1). In the COFCAW process, partial combustion is initiated, followed by injection of water directly into the formation. Steam is generated at the bottom of the well, the subsequent recovery being from a different well as the combination of heat, pressure and steam pushes the now-fluid oil ahead through the unconsolidated and highly permeable sands of the McMurray Formation. The process is similar in many respects to the flooding technology utilized in conventional secondary recovery operations. The advantage gained over the steam injection technique is that water quality requirements are quite low since no steam generating equipment is used. It is not felt that precipitates or even modest sediment build-up in the formation will be a problem. Recycle potential of recovered process water will be high--an estimated ninety per cent--but the total process water needed as a ratio of water to oil is five to one. The recovery rate of water initially injected is not yet known, but it is presumed to be high. Due to the lower demands for water quality in the process, retreatment of the recycle water should prove to be at a minimal expense.

---

[1]"COFCAW" is the acronym for "Combination of Forward Combustion and Water".

The projected internal water balance of a commercial scale plant is useful. This is compared to similar projections for a mining and hot-water extraction operation. (All figures have been projected on the basis of 100,000 barrel per day production capacity (Table 6.3-1).) On the basis of these figures, it is evident that the COFCAW process utilized by Amoco has the lowest consumptive use of water, in spite of the fact that the total water flow requirements for the process are high. Actual consumptive uses may be somewhat higher over the entire life of the project as replacement of formation fluid takes place, but this factor is difficult to determine at this time. The high recycle rates in conjunction with the low water quality parameters are the main causative factors in maintaining this low figure. The relatively large water-to-oil ratio of five to one (as compared to the four to one ratio predicted for the Imperial site) should not result in any large demands for water within a short period of time, as only a few wells will come on stream during relatively short time periods. (This low on-stream demand rate also applies to the Imperial process.)

In the above discussion it is presumed that extensive recycling of used process water will be undertaken. While this is unlikely to prove critical in the COFCAW process (as indicated above), it will be so in the steam injection process. The technology for this recycling is not presently available outside the laboratory; there are tentative plans for a pilot treatment plant. If this recycling should prove impossible for technical or economic reasons, some serious problems of disposal will arise. Effluent from a single commercial scale

steam injection plant could approach 300,000 barrels per day. This is not as severe as the problem anticipated at the Syncrude site, but does approach it in the order of magnitude. If re-use does become a problem, then handling the above-mentioned water supply will become more difficult. For these reasons it is clear that research is needed to better establish a recycling technology which is feasible at a commercial scale.

A number of stages in the development sequence are likely to have adverse effects upon the environment, both within the area of development and outside that area. Most of these effects are related to the water resource either as a causative factor or as an intermediate agent.

One of the most visible of these hazards caused by water is the erosion of soil laid bare during development. This is a function of many factors previously discussed (Chapter V). A special contributing factor at the Amoco site is the seasonal nature of earth-moving activities. Since some of the area is wet or of a muskeg nature, it is necessary to schedule much of the clearing of vegetation and building of drilling pads, roads, et cetera, during the winter months when the frozen ground can support heavy loads. The earth removed and subsequently utilized as fill elsewhere is actually an unconsolidated mass of earth and snow. Warming temperatures in the spring and consequent melting of the frozen portion of the mass make it unstable and subject to erosion and mass movement. These factors, in conjunction with the higher and more rapid run-off to be expected from cleared areas, can lead to extreme erosion problems when clearing is undertaken on a scale

such as that required for a commercial development.

Water is an intermediate agent in a more serious consequence or erosion, that of deposition of eroded material downstream from the point of erosion. Extensive sedimentation can be expected to seriously disrupt the benthic population of a water body, with subsequent impact felt throughout the biologic community. In lowland areas erosion may not reach critical proportions, but in high slope areas or areas immediately adjacent to water bodies, the potential danger is great. This danger is not simply from suspended sediment, but as is the case at the Amoco site, may well involve significant bed load transport.

Several techniques have been employed in alleviating this double-ended problem of erosion and sedimentation. The most promising appears to be the directional drilling practiced by Imperial Oil. This technique minimizes clearing, and so lessens the potential for erosion and siltation. Since the area cleared of vegetation is at a minimum, alteration of soil moisture storage potential is lessened and surface run-off is kept to a minimum. Although institution of directional drilling techniques from consolidated pads will have to be considered individually in each area of development, it could well provide the most important single answer to problems of high surface run-off, erosion and sedimentation, particularly in high slope areas.

Several specific problems have occurred in the experimental areas, and are likely to occur in others as development proceeds. Control of these hazards is often achieved by methods which are simple and

Photo 6.3-1: Settling pond at Texex site. Inclined overflow culvert retains oil film in pond.

Photo 6.3-2: Ditching around perimeter of Texex site to prevent flow into forest.

Photo 6.3-3: Imperial Cold Lake site--minimal clearing needed between drilling pads.

direct, if applied soon after inception of the problem. Several of these are illustrated.

It is evident that, while many of the illustrated techniques are practiced in isolated cases, they are often quite effective within a limited time frame and may be viable components of an over-all management program. It is unlikely that engineering solutions alone will provide a solution to severe problems of erosion and sedimentation. Management practices are likely to be more important in developments in close proximity to water courses. Extreme caution is needed in development of areas where rapid sediment transport is in evidence, and buffer zones substantially greater than those presently planned (Amoco, 1974) may be required. In very low slope areas, a suggested minimum of 100 yards (100 metres) may be sufficient; areas of higher slope may require a margin of two or three times that distance until the effectiveness of preventative measures is proven. This might call for some alteration of the development sequence until more is known about the problem on a site-specific basis. Difficulties with the instability of unconsolidated earth masses will remain a problem in areas where winter construction is necessary.

## 6.4 Environmental Enhancement:

Discussion of alteration of the environment related to development of the oilsands has to this point been limited to reference to the potentially damaging effects of development upon the environment.

The greater portion of the literature devoted to the environmental effects of development has centered upon the ultimate restoration of an ecosystem as closely as is possible to that in existence prior to development. While this stance is certainly valid in locations with a highly productive environment, it should be open to question in areas where the possibility of significant improvement exists on a long term basis. Alteration of the environment through development and consequent reclamation could simply improve the over-all quality of the land for the present extensive uses at one end of the spectrum. At the other end, a total alteration of the environment might render it fit for a variety of uses. Both the public and private sectors might utilize the land for both intensive activities and additional extensive uses.

The areas of unbroken boreal forest and muskeg present in the Athabasca region have very low carrying capacities for most forms of wildlife. While the heavy forest cover may provide sanctuary for some species, it generally does not provide forage. Muskeg may also serve as a refuge for some species, especially waterfowl. But again, the species of vegetation present are not ideal for feeding purposes because of the acidic waters. The water resource of muskeg and associated areas is not conducive to the maintainence of good fisheries, mainly due to the high BOD associated with the organic material in these areas. Those ungulates most able to survive in this environment (moose) are generally found to avoid it if other habitat are available. Carrying capacity for most wildlife is quite low for both the thick forest cover and the muskeg (Ecological Investigations, Peace-Athabasca

Delta Study, 1973).

The sequence involved in oilsands development is initiated as mentioned previously, by some degree of clearing. The creation of cleared areas may, as has been the case elsewhere in Alberta, increase the carrying capacity for wildlife. An increase in forage will prove especially beneficial to ungulates. Movement of heavy equipment and establishment of drilling pads will also involve the draining of areas of muskeg. The creation of these well drained clearings or of better forest cover through site improvement will lead to an environment that is capable of supporting a greater range and larger numbers of wildlife. The network of roads and clearings will make it more accessible for human use.

Present surface water quality is also a problem in many areas of the oilsands regions. Relatively shallow water bodies with little through-flow and high organic content have eutrophication rates which preclude intensive use of the water bodies for fisheries or water-based recreation. Since run-off from muskeg areas in many years contributes significantly to these relatively closed basins, the draining of some muskegs could be managed so as to contribute to more useful water quality. Conversely, some of the water bodies with a higher through-flow (eg. the Athabasca River) have an extremely low dissolved solids content. Since the application of chemical fertilizers during revegetation will inevitably lead to some increase in solutes in surface run-off, research might well indicate the encouragement of this sort of "planned pollution" in some drainage basins, provided this

added solute load could be used to advantage by the lifeforms present in the water body (Hallock, 1975). If the surface water supplies can benefit from either of the two general approaches cited above, then planned alteration of water quality might well be managed as an integral part of the desired sequence of development and reclamation in the oilsands areas.

Development of the oilsands areas and their subsequent modification during reclamation might well be oriented toward permanent alteration of the environment if viable alternative uses for the land can be maintained. No concrete proposals for alternative use exists at the present time, but a number of possibilities might be suggested. Many uses of the land (e.g. recreation) are now precluded due to the inaccessability of the various resources. Part of the network of roadways necessary for oilsands development might be maintained and used for access to parks, cottages, or other developments requiring somewhat of a wilderness setting. For instance, a ski area has been suggested for Stony Mountain which might well be integrated with some of the construction required by Amoco for their enlarged pilot operations (Amoco, 1973). Ease of access has also been suggested as an incentive to establishing some forestry in the area, along with the associated industry. The encouragement of a tourist industry in the Athabasca area would certainly be in line with provincial policy which favors development of industries outside the non-renewable resources sphere. Other potential uses may well exist which are likely to be far more desirable than simply returning the environment to its relatively

unattractive and almost useless present condition.

The Peace River and Cold Lake deposits are situated in regions with attributes somewhat more conducive to alternative or multiple uses. In view of this flexibility, and in view of the relative nearness of these regions to population centers, some over-all land use planning should be of high priority. Many potential conflicts exist, but a planned sequence and style of development may well turn some of these potential conflicts into complementary activities or constructive stages of development. As mentioned above, recreation and forestry could rank high among these uses, as well as improvement of wildlife habitat and in some instances even marginal agricultural production. The potential for these activities does exist. Several of the oil companies involved in exploiting the oilsands in these regions have shown their willingness to cooperate in conjunctive planning in the very early stages. This cooperative spirit could be fostered and used to public advantage if the provincial government would clarify policies on a lease specific basis well in advance of the pilot plant construction phase. The present policy of reclamation of land to its previous level of productivity is very limited in its objectives. Modification of this policy should be examined, with new objectives of maximization of environmental productivity and alternative use.

# Chapter VII

## Conclusions and Recommendations

## 7.1 Alberta's Oilsands Areas:

A number of general environmental conflicts are apparent at this early stage of in-situ oilsands development. Perhaps the greatest environmental danger associated with development will be that related to damage in the quality of water resources of the oilsands areas. The problems associated with erosion and sedimentation are the most evident of these at present. Pre-development clearing will alter regime and yield patterns, thus aggravating the erosion problem. Water supply may also be a problem for individual projects, as will the danger of pollution from effluent disposal. The potential for land use conflicts will increase, especially as the more southerly oilsands deposits come under development. Finally, the possibility of enhancing the productivity of present environments should be investigated. The need for early research concerning this and other problems is evident.

Perhaps the most pressing research need is the establishment of an internal water budget for each in-situ development program so that water supply and disposal relationships might be determined. It will be necessary to have a much more precise estimate of process water requirements than that provided in Section 6.4. The need for a commercially feasible process water recycling technology is apparent. This need has not yet been met, and will be critical to both supply and disposal. This should receive early priority. An external water balance management program will also be required, since it is evident that the alteration

of the watershed necessary for development will drastically change total yield, regime, flooding, erosion and sedimentation patterns. Once the internal and external water balances are known, it will be possible to develop an integrated water budget for each site. In this manner the maximum use can be made of on-site surpluses and a minimum level of disposal problems can be achieved.

The problem of erosion and sedimentation is closely related to site selection. The most important facet of any erosion control program will be the avoidance of high slope locations. Most of the oilsands reserves are under relatively flat topography. Judicious site selection procedures would result in location of initial developments in the flatter areas. This would allow the initiation, evaluation and modification of erosion control programs without the added hazards associated with use of the steeper slopes. Areas of greater relief could later be exploited with more assurance of success in reclamation and erosion control.

Erosion on the present test sites has been initiated by the removal of vegetation. The erosion of the unprotected soil has been accelerated by rapid run-off from the cleared areas (Section 5.4). The use, where possible, of directional drilling techniques such as those currently employed at the Imperial Cold Lake sites would minimize the area of denudation. The importance of the resulting buffer zones of natural vegetation is manifest. These strips of vegetation are necessary for limiting sediment transport. Maintainence of substantial buffer zones of natural vegetation (up to 300 yards or about 300 metres

in steeper areas) is required bordering all stream channels, river banks, incised water-courses and lakes. This requirement is quite attainable in most oilsands areas because most surfaces are relatively flat and stream densities are not great.

The consequences of oilfield construction without proper reclamation planning is evident in the Swan Hills of Alberta. The impact of careless development upon regime patterns and yield capabilities probably has not been great because most areas remain uncleared but the problem of erosion and sedimentation around well sites and along service roads has been severe. Two recommendations applicable to oilsands development might be based upon studies in this area (Section 5.2). The first of these is that development of high slope areas must be avoided where possible. (A precise definition of what constitutes "high slope" will have to be done on a site specific basis, depending upon the geomorphic and other characteristics of each site.) The other recommendation is based upon the greater success of preventative erosion control measures than of corrective measures. Implementation of corrective measures only on the scale anticipated for commercial in-situ development will probably prove both expensive and ineffective. Thus the second recommendation is the development of a revegetation and erosion reduction program prior to the initiation of development and in phase with the several stages of construction.

Development of oilsands reserves may well involve conflicts in land use. Forestry and agriculture may be viable alternative uses of land in some areas, although these uses are not totally irreconcilable

with short-term in-situ development. However, the most prominent present conflicts are with outdoor recreation and wildlife. Some cases, such as the Amoco Gregoire Lake site or Gulf Oil's Cold Lake Project, involve direct conflict with optimal use of present or planned provincial parks. This conflict may involve maintenance of easily quantifiable aspects of the environment (e.g. water quality at Gregoire Lake). The more elusive aesthetic values also may require consideration (e.g. screening in-situ installations from proposed park facilities). The value of early conjunctive planning has been made clear by the excellent efforts of Gulf Oil in respect to proposed park facilities near the Medley River at Cold Lake. Since these conflicts will occur more frequently as in-situ development increases, more planning of this nature will be required.

Many of Alberta's recreational resources are as yet undeveloped. It should be possible to identify these areas and provide some early integrated planning to guard against degradation of zones with high park use potential. Several in-situ projects in the Cold Lake area are proposed for zones of high recreational potential and similar potential exists at the site planned for development by Numac Oil and Gas, Ltd., on the Stony Mountain Plateau. Proper planning will provide safeguards for these areas, in addition to access to previously isolated recreational sites (e.g. Surmont Lake). Similar conflicts and opportunities for use enhancement will occur as more oilsands developments are proposed, and should be dealt with on individual bases.

7.2 The Gregoire Lake Area:

Gregoire Lake is a valuable resource in the Ft. McMurray area, unique because of its quality and accessibility. The watershed which maintains Gregoire Lake presently provides good quality flow and has a relatively high yield for this region. In-situ experimental work in this basin will soon include expansion of the Amoco Gregoire Lake Experimental Site to the pilot plant phase. Additional experimental work by Numac Oil and Gas, Ltd., will soon begin on the Stony Mountain Plateau. These projects have recently received substantial funding from AOSTRA, and further development is assured (Edmonton Journal, June 11, 1976). It is not likely that development at this scale will greatly endanger water quality in the Gregoire Lake Basin. However, commercial scale development at these sites would very likely result in major deterioration of water quality, increase yields, cause extreme fluctuation in regime, and cause significant increases in flooding, erosion and sedimentation. Degradation of these aspects of the water resource will have an adverse effect upon the use potential of Gregoire Lake Provincial Park. Unplanned development on Stony Mountain could seriously disrupt over-all water quality in the lower basin. The recreational potential of the many lakes on the Stony Mountain Plateau could be endangered by in-situ activities. A closer investigation of the sites proposed for development by Numac Oil and Gas, Ltd., is required if the potential hazards are to be more closely defined. Commercial scale development in either of these areas will considerably lessen the

the recreational potential of the Gregoire Lake area if major damage preventative measures are not undertaken.

Particular note should be made of the poor site selection for the present experimental work of Amoco (Chapter V). This is a high slope area, with a consequent high erosion potential. The proximity of Surmont Creek, with resulting danger to the creek and to Gregoire Lake from sedimentation, is also a dangerous situation. Should future larger scale developments cause erosion similar to that which has already occurred, but on a larger scale, the planned safeguards are not likely to be adequate for protection of Gregoire Lake.

The Gregoire Lake Basin has a number of sites that have fewer hazards associated with development. The above-mentioned plateau or the low plain surrounding but somewhat removed from Gregoire Lake do not have the potential problems of the escarpment face. Development of the escarpment, and particularly those zones near stream channels, should be discouraged until a proven erosion prevention technology is available. It is probable that present development technology will result in damage that will be prohibitively expensive to control in high slope areas. Directional drilling will minimize this danger, but a substantial hazard will still exist. Any development on the escarpment face which involves clearing of vegetation (this includes road building) should be discouraged at present.

An integrated water budget study is needed for each of the proposed in-situ developments in the Gregoire Lake Basin. Water supply and disposal requirements are not likely to be met by the present supply

and disposal well techniques. Particular emphasis should be put upon effects of the water surplus increases at each site on Surmont Creek and Gregoire Lake. More information is needed, however, on the details of the internal water budgets of the plants. This should soon become available through AOSTRA. The material in this report is preliminary and may serve as a basis for a future integrated site water balance.

## 7.3 General Program Needs:

Current trends in research are that in-situ development will become the dominant technology in the development of the oilsands of Alberta sooner than was thought likely a few years ago. Government commitments to research, both internal and through funding of private research, are recent evidence of this trend (Edmonton Journal, June 11, 1976). This research will be primarily oriented toward development of an efficient process technology. In contrast, very little research has been done relative to the effects of in-situ developments upon the environment. Conflicts in land use are inevitable, with watersheds and water resources being among the more important areas of potential dispute. The establishment of research programs in several areas is needed.

An environmental impact statement should be required prior to the initiation of any development. This should be written in conjunction with a comprehensive reclamation plan integrated with all stages of development with final plans being subject to periodic review. The danger inherent here is the probable inability of the government to

deal swiftly and efficiently with individual cases. A streamlined review mechanism will be needed. Another danger is that reclamation will be interpreted to mean restoration of the original environment. This is not a reasonable interpretation. Emphasis should be placed upon the establishment of a productive environment. A variety of land use alternatives might be more productive than the present uses of the environment, but long term enhancement of renewable resources would be the most desirable alternative.

A mapping of present and potential alternative land uses would be valuable as part of a preliminary program. Probable land use conflicts in the oilsands areas could then be anticipated in advance of development planning. This mapping should be done in a lease and site-specific basis. Particular attention to the recreational potential of the areas is merited.

The present body of reclamation knowledge in in-situ development is much superior to the practice in any individual reclamation plan currently in existence. Consequently, a pooling of reclamation technology and related information is desirable. There is a potential for this to be accomplished in the private sector. However, since it is desirable to integrate reclamation with the development sequence, close association of reclamation technology with development technology is the most practical solution. The most likely agency for this associated study and development would be AOSTRA, since it will be involved in most of the processes involved in in-situ development. Emphasis should be put upon the direct involvement of private industry regardless of the

final constitution of the agency. Finally, it is recognized that reclamation research takes time. Evaluation may be possible only several seasons after implementation. Therefore, early initiation of a common reclamation data pool and cooperative research program is recommended.

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Appendix A

Glossary

Glossary:

Many aspects of this thesis are drawn from disciplines outside the field of geography. Many of the terms used are thus unfamiliar to geographers and as such need some explanation. Since this thesis is intended for use by those outside the field of geography, conversely the geographic jargon may be unfamiliar to the reader. The following explanatory notes are intended for use by those unfamiliar with some of this terminology.

baseline conditions - the range of normal or natural environmental conditions in an area. The early establishment of this range providing a stationary basis or "baseline" against which fluctuations in environmental conditions can be measured.

BOD (Biological Oxygen Demand) - a measure of water quality for determination of the supply and demand for dissolved oxygen by organisms within a water body.

deficit - when soil moisture storage has been totally depleted by actual evapotranspiration, yet the potential for evapotranspiration still exists, this diffe ence between actual evapotranspiration and potential evapotranspiration is accumulated as a soil moisture deficit.

dry years - unit area run-off in certain years is less than that of the long term average. This may be a result of modest precipitation,

low soil moisture recharges during the previous year, or both (see "wet years").

eutrophication - the gradual enrichment of a water body with nutrients essential to plant growth. This aging process can be accelerated by man's activities. (e.g. the addition of phosphates)

evapotranspiration - the combined loss to the atmosphere of evaporation from land and water surfaces in addition to transpiration from organic material.

in-situ - (in reference to the oilsands) production is achieved from the formation as it is situated underground, rather than removing the formation (by strip-mining) for processing in a plant.

Landsat (formerly ERTS) - either of two multiband remote sensing satellites in polar syncronous orbits. Total coverage of the earth is presently achieved every nine days.

long term records - (in reference to meteorological data) this is a relative term indicating that the record is over a period long enough to prevent any single anomolous occurrence from significantly altering the average of all the data. The minimum for a single meteorological station is considered to be on the order of thirty years. However considerable use can be made of shorter runs of data if it can be supported by longer term data from nearby stations.

microdensitometer - in the jargon of remote sensing, the instrument used in "density slicing". This instrument is able to differentiate tonal variation about three times as precisely as the human eye.

orographic precipitation - air which is forced to rise over landforms is subject to cooling, resulting in condensation and finally precipitation. Orographically induced precipitation is normally greater than that which would ordinarily occur.

oilsands - deposits of asphalt oil deposits in Northern Alberta (and elsewhere in the world). The oil is so viscous that it is not recoverable by conventional--that is, by drilling and pumping--techniques.

precipitates - various aspects of in-situ technology require the generation of steam. During the change of state from water to steam, dissolved solids are left behind as deposits on the generating equipment.

soil moisture storage - that portion of precipitation intercepted by the earth which remains within reach of vegetation for use in evapotranspiration falls within this storage category. The storage capacity of a particular soil is determined partially by permeability rates and porosity and partially by rooting depth of vegetation.

surplus - any precipitation which falls upon saturated soil--that is, soil moisture storage categories which are at capacity--is calculated as a surplus in the water balance equation.

water quality - this term is meaningless unless some desired quality parameters can be established. This in turn demands that the proposed use of the water be known. In this thesis, water quality is used as a relative term, "good" quality being that which will suffice for anticipated use categories.

wet years - unit area run-off in certain years exceeds that of the long term average. This may be the result of unusually great precipitation, substantial soil moisture carry-over from the previous year, or both. Even relatively modest precipitation may result in large surpluses if soil moisture storage capacity is saturated.

Appendix B

Drainage Basin Characteristics

There are a number of differences between the basins of Gregoire Creek and the Hangingstone River which help explain the observed flow characteristics. These are broken down in the following table as predominantly physical or predominantly climatic in nature. The two streams are then evaluated relative to each other. In some cases, the basin characteristic should have a hydrologic effect opposite to what was in fact observed. It is likely that these characteristics were a moderating influence on the more dominant factors in the flow regime. These contrary characteristics are indicated by an asterisk. Differences resulting from actual evapotranspiration from vegetative cover are not included.

Basin Characteristics of Gregoire Creek and the Hangingstone River

| Basin Characteristics | Gregoire Creek | Hangingstone River |
|---|---|---|
| Basin shape | Elongate: no single large area contributes to discharge at any point in time. | Pear-shaped: tributaries contribute to flow concentrations. |
| Stream Length/ Basin Size * | Short length/small basin Flashier flow, faster response expected. | Point of gauging removed from main catchment area. Greater length/larger basin. |
| Overland Flow | Probably greater, especially in upper basin. | Well drained, defined drainage network. |
| Relief* | Greater relative relief-rapid stream response not present, however. | Low relief in most of basin, but some areas of high slope. |
| Channel Cross-section | Meandering; deep channel in most sections. Large channel storage capacity. | Straighter; shallower, rocky channel. Less storage capacity. |
| Vegetative Cover | Mixed forest, aspen-poplar. Significant muskeg area resulting in slower run-off response, greater unit-area discharge. | Similar. Less muskeg, probably more recently burned-over area. |
| Soil Patterns | Gray wooded; parent material more glacial till. | Similar; parent material somewhat more lacustrine. |
| Bedrock | Similar | Similar |
| Surface Detention Storage | Very high: much open muskeg, many small lakes, Gregoire Lake. 15% of basin is surface water. | Average: some lakes and muskeg typical of region. Less than 5% surface water. |

(continued)

Basic Characteristics of Gregoire Creek and the Hangingstone River

| Basin Characteristics | Gregoire Creek | Hangingstone River |
|---|---|---|
| Land Use | Similar | Similar |
| Precipitation: | | |
| Type: | Greater snow component, gradual discharge with snowmelt. | Less snow pack owing to lower elevation. |
| Duration: | Longer storm duration seems likely, although no records. | Shorter storms - less yield. |
| Frequency: | Storm frequency slightly greater. | Fewer storms at lower elevations. |
| Intensity: | More storms of intense nature. | As intense, but less frequently so. |
| Total: | Greater unit-area precipitation. | Less precipitation over most of the basin. |
| Evapotranspiration | Lower mean temperatures, especially in upper basin. | Higher daytime maximums. Greater overall PE. |
| Elevation | Greater: most of the above climatic features are a result of orographic influences. | Elevation as great in upper parts, but most of basin at lower elevation. |
| Aspect | Contains north-facing slope of Stony Mountain | Generally west facing. |

## Appendix C

## Water Balance Tables

Anzac - 1975 (English Units)

| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| oF | -1.2 | 4.0 | 14.8 | 34.6 | 48.6 | 56.3 | 63.9 | 55.3 | 49.8 | 36.6 | 18.1 | 4.5 | 32.1 |
| I | 0 | 0 | 0 | .15 | 2.53 | 4.50 | 6.79 | 4.22 | 2.81 | .36 | 0 | 0 | 21.36 |
| UPE | | | | .01 | .07 | .10 | .13 | .09 | .08 | .02 | 0 | 0 | |
| PE" | 0 | 0 | 0 | .35 | 2.79 | 4.08 | 5.34 | 3.58 | 2.54 | .55 | 0 | 0 | 19.23 |
| Ppt. | 1.46 | .22 | 1.11 | 1.44 | 3.31 | 3.12 | 5.21 | 3.99 | 3.16 | 1.63 | .88 | .87 | 26.40 |
| S.C. | +1.46 | +.22 | +1.11 | +1.09 | + .52 | - .96 | - .13 | + .41 | + .62 | +1.08 | + .88 | +.87 | |
| St. 1/2" | | | | | | | | | | | | | |
| (1.71) | .50 | .50 | .50 | .50 | .50 | 0 | 0 | .41 | .50 | .50 | .50 | .50 | |
| Surp. | 1.46 | .22 | 1.11 | 1.09 | .52 | -- | -- | -- | .53 | 1.08 | .88 | .87 | 6.05 |
| Def. | | | | | | .46 | .13 | | | | | | .59 |
| St. 2" | | | | | | | | | | | | | |
| (.21) | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.04 | .91 | 1.32 | 1.94 | 2.0 | 2.0 | 2.0 | |
| Surp. | 1.46 | .22 | 1.11 | 1.09 | .52 | | | | | 1.02 | .88 | .87 | 5.63 |
| Def. | | | | | | | | | | | | | |
| St. 4" | | | | | | | | | | | | | |
| (2.21) | 3.67 | 3.89 | 4.0 | 4.0 | 4.0 | 3.04 | 2.91 | 3.32 | 3.94 | 4.0 | 4.0 | 4.0 | |
| Surp. | | | 1.0 | 1.09 | .52 | | | | | 1.02 | .88 | .87 | 3.63 |
| Def. | | | | | | | | | | | | | |
| St. 6" | | | | | | | | | | | | | |
| (3.27) | 4.73 | 4.95 | 6.0 | 6.0 | 6.0 | 5.04 | 4.91 | 5.32 | 5.94 | 6.0 | 6.0 | 6.0 | |
| Surp. | | | .06 | 1.09 | .52 | | | | | 1.02 | .88 | .87 | 2.69 |
| Def. | | | | | | | | | | | | | |
| St. 10" | | | | | | | | | | | | | |
| (7.27) | 7.27 | 7.95 | 10.0 | 10.0 | 10.0 | 9.04 | 8.91 | 9.32 | 9.94 | 10.0 | 10.0 | 10.0 | |
| Surp. | | | .06 | 1.09 | .52 | | | | | 1.02 | .88 | .87 | 2.69 |
| Def. | | | | | | | | | | | | | |

Anzac - 1975 (Metric Units)

| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | -18.4 | -15.6 | -9.6 | 1.4 | 9.2 | 13.5 | 17.7 | 12.9 | 9.9 | 2.6 | -7.7 | -15.3 | 0.1 |
| PEmm | 0 | 0 | 0 | 8.9 | 70.9 | 103.6 | 135.6 | 90.9 | 64.5 | 14.0 | 0 | 0 | 488.4 |
| Ppt. | 37.1 | 5.6 | 28.2 | 36.6 | 84.1 | 79.2 | 132.2 | 101.3 | 80.3 | 41.4 | 22.4 | 22.1 | 670.6 |
| S.C. | 37.1 | 5.6 | 28.2 | 27.7 | 13.2 | 24.4 | 3.3 | 10.4 | 15.7 | 27.4 | 22.4 | 22.1 | |
| St.10mm | | | | | | | | | | | | | |
| (43.4) | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | | | 10.4 | 12.5 | 12.5 | 12.5 | 12.5 | |
| Surp. | 37.1 | 5.6 | 28.2 | 27.7 | 13.2 | -- | -- | -- | 13.3 | 27.4 | 22.4 | 22.1 | 240.4 |
| Def. | | | | | | 11.9 | 3.3 | | | | | | 15.2 |
| St. 50mm | | | | | | | | | | | | | |
| (5.3) | 50 | 50 | 50 | 50 | 50 | 25.6 | 22.3 | 32.7 | 48.4 | 50.0 | 50 | 50 | |
| Surp. | 37.1 | 5.6 | 28.2 | 27.7 | 13.2 | | | | | 25.8 | 22.4 | 22.1 | 187.4 |
| Def. | | | | | | | | | | | | | |
| St. 100mm | | | | | | | | | | | | | |
| (56.1) | 57.3 | 94.4 | 100 | 100 | 100 | 75.6 | 72.3 | 82.7 | | 100 | 100 | 100 | |
| Surp. | | | 25.0 | 27.7 | 13.2 | | | | | 25.8 | 22.4 | 22.1 | 192.3 |
| Def. | | | | | | | | | | | | | |
| St. 150mm | | | | | | | | | | | | | |
| (83.1) | 107.3 | 144.4 | 150 | 150 | 150 | 125.6 | 122.3 | 132.7 | 148.4 | 150 | 150 | 150 | |
| Surp. | | | 5.6 | 27.7 | 13.2 | | | | | 25.8 | 22.4 | 22.1 | 199.9 |
| Def. | | | | | | | | | | | | | |
| St. 250mm | | | | | | | | | | | | | |
| (184.7) | 207.3 | 244.4 | 250 | 250 | 250 | 225.6 | 222.3 | 232.7 | 248.4 | 250 | 250 | 250 | |
| Surp. | | | 5.6 | 27.7 | 13.2 | | | | | 25.8 | 22.4 | 22.1 | 301.5 |
| Def. | | | | | | | | | | | | | |

Ft. McMurray - 1975 (English Units)

| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °F | -2.7 | -12.4 | 14.7 | 35.1 | 49.2 | 57.1 | 64.4 | 56.1 | 50.0 | 37.5 | 16.9 | 2.1 | 30.7 |
| I | | | | .20 | 2.67 | 4.72 | 6.95 | 4.44 | 2.86 | .47 | | | 22.31 |
| UPE | | | | .02 | .08 | .10 | .13 | .10 | .08 | .03 | | | 19.23 |
| PE" | | | | .69 | 3.19 | 4.08 | 5.34 | 3.75 | 2.54 | .83 | | | 20.42 |
| Ppt." | 1.00 | .31 | .65 | 1.13 | 2.77 | 3.57 | 2.82 | 4.69 | 3.58 | 1.39 | .56 | 1.04 | 22.38 |
| S.C. | +1.00 | + .31 | + .65 | + .44 | - .42 | - .51 | -2.52 | + .94 | +1.04 | + .56 | + .56 | +1.04 | |
| St. 1/2" | | | | | | | | | | | | | |
| (1.71) | .50 | .50 | .50 | .50 | .08 | 0 | | .50 | .50 | .50 | .50 | .50 | |
| Surp. | 1.00 | .31 | .65 | .44 | | | | .44 | 1.04 | .56 | (.56) | (1.04) | 6.15 |
| Def. | | | | | | .43 | 2.52 | | | | | | 2.95 |
| St. 2" | | | | | | | | | | | | | |
| (.21) | 2.0 | 2.0 | 2.0 | 2.0 | 1.58 | 1.07 | 0 | .94 | 1.98 | 2.0 | 2.0 | 2.0 | |
| Surp. | .23 | .31 | .65 | .44 | | | | | | .54 | ( .56) | (1.04) | 2.37 |
| Def. | | | | | | | 1.45 | | | | | | 1.45 |
| St. 4" | 2.23 | 2.54 | 3.19 | 3.63 | 3.21 | 2.70 | .18 | 1.12 | 2.16 | 2.72 | 3.28 | 4.0 | |
| Surp. | | | | | | | | | | | | (.32) | 0 |
| Def. | | | | | | | | | | | | | 0 |
| St. 6" | 2.57 | 2.88 | 3.53 | 3.97 | 3.55 | 3.04 | .52 | 1.46 | 2.50 | 3.06 | 3.62 | 4.66 | |
| Surp. | | | | | | | | | | | | | 0 |
| Def. | | | | | | | | | | | | | 0 |
| St. 10" | 6.57 | 6.88 | 7.53 | 7.97 | 7.55 | 7.04 | 4.52 | 5.46 | 6.50 | 7.86 | 7.62 | 8.66 | |
| Surp. | | | | | | | | | | | | | 0 |
| Def. | | | | | | | | | | | | | 0 |

Ft. McMurray - 1975 (Metric Units)

| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $^{o}C$ | -19.3 | -24.6 | -9.6 | 1.7 | 9.5 | 13.9 | 18 | 13.4 | 10 | 31.0 | -8.4 | -16.6 | -0.7 |
| PEmm | | | | 17.5 | 81.0 | 103.6 | 135.6 | 95.3 | 64.5 | 21.1 | | | 518.7 |
| Ppt.mm | 25.4 | 7.9 | 16.5 | 28.7 | 70.4 | 90.7 | 70.6 | 119.1 | 90.9 | 35.3 | 14.2 | 26.4 | 568.5 |
| S.C. | 25.4 | 7.9 | 16.5 | 11.1 | 10.7 | 13.0 | 64.0 | 23.9 | 26.4 | 14.2 | 14.2 | 26.4 | |
| St. 12.5mm (43.4) | 12.5 | 12.5 | 12.5 | 12.5 | 1.8 | | | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | |
| Surp. | 25.4 | 7.9 | 16.5 | 11.1 | | | | 11.4 | 26.4 | 14.2 | 14.2 | 26.4 | 196.9 |
| Def. | | | | | | 11.2 | 65.2 | | | | | | 76.4 |
| St. 50mm (5.3) | 50 | 50 | 50 | 50 | 39.3 | 26.3 | 0 | 23.9 | 49.9 | 50 | 50 | 50 | |
| Surp. | 5.4 | 7.9 | 16.5 | 11.1 | | | | | | 14.2 | 14.2 | 26.4 | 101.0 |
| | | | | | | | 37.7 | | | | | | 37.7 |
| St. 100mm | 55.4 | 63.3 | 79.8 | 90.9 | 80.2 | 67.2 | 3.2 | 27.1 | 53.5 | 67.7 | 81.9 | 100 | |
| | | | | | | | | | | | | 8.3 | 0. |
| | | | | | | | | | | | | | 0. |
| St. 150mm | 65.3 | 73.2 | 89.5 | 100.6 | 89.9 | 76.9 | 12.9 | 36.8 | 63.2 | 77.4 | 91.6 | 117.0 | |
| Surp. | | | | | | | | | | | | | 0. |
| Def. | | | | | | | | | | | | | 0. |
| St. 250mm | 165.3 | 173.2 | 189.5 | 200.6 | 189.9 | 176.9 | 112.9 | 136.8 | 163.2 | 177.4 | 191.6 | 117.0 | |
| Surp. | | | | | | | | | | | | | 0. |
| Def. | | | | | | | | | | | | | 0. |

Stony Mountain LO - 1975 (English Units)

| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °F | -2.9 | 2.3 | 13.1 | 32.9 | 46.8 | 54.3 | 62.7 | 53.0 | 48.7 | 34.9 | 16.4 | 2.8 | |
| I | | | | .03 | 2.13 | 3.95 | 6.41 | 3.60 | 2.55 | .18 | | | 18.85 |
| UPE | | | | 0 | .06 | .09 | .12 | .09 | .07 | .02 | | | |
| PE" | | | | 0 | 2.39 | 3.67 | 4.93 | 3.38 | 2.23 | .55 | (13.48) | | 17.15 |
| Ppt." | 1.69 | .25 | 1.39 | 1.67 | 3.81 | 4.11 | 5.94 | 5.10 | 2.97 | 1.89 | 1.92 | 1.01 | 30.85 |
| S.C. | 1.69 | .25 | 1.39 | 1.67 | 1.42 | .44 | 1.01 | 1.72 | .74 | 1.34 | 1.02 | 1.01 | |
| St. 1/2" | | | | | | | | | | | | | |
| (2.07) | .50 | .50 | .50 | .50 | .50 | .50 | .50 | .50 | .50 | .50 | .50 | .50 | |
| Surp. | 1.69 | .25 | 1.39 | 1.67 | 1.42 | .44 | 1.01 | 1.72 | 2.97 | 1.89 | (1.02) | (1.01) | 13.74 |
| Def. | | | | | | | | | | | | | 0 |
| St. 2" | | | | | | | | | | | | | |
| (127) | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | |
| Surp. | 1.69 | .25 | 1.39 | 1.67 | 1.42 | .44 | 1.01 | 1.72 | 2.97 | 1.89 | (1.02) | (1.01) | 12.94 |
| Def. | | | | | | | | | | | | | 0 |
| St. 4" | | | | | | | | | | | | | |
| (1.27) | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | |
| Surp. | 1.69 | .25 | 1.39 | 1.67 | 1.42 | .44 | 1.01 | 1.72 | 2.97 | 1.89 | (1.02) | (1.01) | 12.94 |
| Def. | | | | | | | | | | | | | 0 |
| St. 6" | | | | | | | | | | | | | |
| (1.27) | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | 6.0 | |
| Surp. | 1.69 | .25 | 1.39 | 1.67 | 1.42 | .44 | 1.01 | 1.72 | 2.97 | 1.89 | (1.02) | (1.01) | 12.94 |
| Def. | | | | | | | | | | | | | 0 |
| St. 10" | | | | | | | | | | | | | |
| (1.27) | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | |
| Surp. | 1.69 | .25 | 1.30 | 1.67 | 1.42 | .44 | 1.01 | 1.72 | 2.97 | 1.89 | (1.02) | (1.01) | 12.94 |
| Def. | | | | | | | | | | | | | 0 |

Stony Mountain LO - 1975 (Metric Units)

| | J | F | M | A | M | J | J | A | S | O | N | D | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | -19.4 | -16.5 | -10.5 | 0.5 | 8.2 | 12.4 | 17.1 | 11.6 | 9.3 | 1.6 | -8.7 | -16.2 | -0.9 |
| PEmm | | | | | 60.7 | 93.2 | 125.2 | 85.8 | 56.6 | 14.0 | | | 435.6 |
| Ppt.mm | 42.9 | 6.4 | 35.3 | 42.4 | 96.8 | 104.4 | 150.9 | 129.5 | 75.4 | 48.0 | 48.8 | 25.9 | 783.6 |
| S.C | 42.9 | 6.4 | 35.3 | 42.4 | 36.1 | 11.2 | 25.7 | 43.7 | 18.8 | 34.0 | 25.9 | 25.9 | |
| St. 12.5mm | | | | | | | | | | | | | |
| (52.6) | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | 12.5 | |
| Surp. | 42.9 | 6.4 | 35.3 | 42.4 | 36.1 | 11.2 | 25.7 | 43.7 | 18.8 | 34.0 | 25.9 | 25.9 | 400.9 |
| Def. | | | | | | | | | | | | | 0. |
| St. 50mm | | | | | | | | | | | | | |
| (32.3) | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | |
| Surp. | | | | | | | | | | | | | 380.6 |
| Def. | | | | | | | | | | | | | 0. |
| St. 100mm | | | | | | | | | | | | | |
| (32.3) | | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | |
| Surp. | 42.9 | 6.4 | 35.3 | 42.4 | 36.1 | 11.2 | 25.7 | 43.7 | 18.8 | 34.0 | 25.9 | 25.9 | 380.6 |
| Def. | | | | | | | | | | | | | 0. |
| St. 150mm | | | | | | | | | | | | | |
| (32.3) | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | 150 | |
| Surp. | | | | | | | | | | | | | 380.6 |
| Def. | | | | | | | | | | | | | 0. |
| St. 250mm | | | | | | | | | | | | | |
| (32.3) | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | 250 | |
| Surp. | | | | | | | | | | | | | 380.6 |
| Def. | | | | | | | | | | | | | 0. |

Appendix D

Snow Survey

Supplementary Snow Survey of the Gregoire Lake Area

| | | Weight | | Depth | |
|---|---|---|---|---|---|
| | | (oz) | (gms) | Inches | mm. |
| Stony Mountain Plateau | 1 | 4.5 | 128 | 16.5 | 41.9 |
| | 2 | 4.0 | 113 | 13.5 | 34.3 |
| | 3 | 2.5 | 71 | 10 | 25.4 |
| | 4 | 1.5 | 43 | 6.0 | 15.2 |
| | 5 | 1.5 | 43 | 4.5 | 11.4 |
| | 6 | 2.5 | 71 | 8.5 | 21.6 |
| | Average | 2.75 | 78 | 9.83 | 25.0 |
| Stony Mountain Escarpment | 1 | 3.0 | 85 | 10.5 | 26.7 |
| | 2 | 2.5 | 71 | 8.0 | 20.3 |
| | 3 | 3.5 | 99 | 11.0 | 27.9 |
| | 4 | 2.0 | 57 | 7.0 | 17.8 |
| | 5 | 2.5 | 71 | 9.0 | 22.9 |
| | 6 | 2.5 | 71 | 10.5 | 26.7 |
| | Average | 2.67 | 76 | 9.33 | 23.7 |
| Gregoire Lake Backshore | 1 | 1.0 | 28 | 3.0 | 7.6 |
| | 2 | 1.5 | 43 | 5.0 | 12.7 |
| | 3 | 1.5 | 43 | 5.0 | 12.7 |
| | 4 | 1.0 | 28 | 4.0 | 10.2 |
| | 5 | 1.5 | 43 | 5.5 | 14.0 |
| | 6 | 0.0 | 0 | 0 | 0.0 |
| | Average | 1.08 | 31 | 3.75 | 9.5 |

Note: sampler used was Mount Rose type snow sampler. Snow density was constant throughout study area.

1 oz = 28.35 gm

Appendix E

Theoretical Yield Patterns

Theoretical Yield Patterns
(Metric Conversions in Brackets)

| | Present | Altered |
|---|---|---|
| 1970 | 10,237 afy<br>(1,264.5 hmy) | 17,504 afy<br>(2,162.2 hmy) |
| 1971 | 7,145<br>(882.6) | 10,677<br>(1,318.9) |
| 1972 | 11,777<br>(1,454.8) | 22,257<br>(2,749) |
| 1973 | 13,847<br>(1,710.5) | 21,661<br>(2,675.7) |
| 1974 | 21,563<br>(2,663.6) | 22,483<br>(2,777.2) |
| 1975 | 3,085<br>(381.1) | 6,245<br>(771.4) |

afy = acre feet per year
hmy = hectare metres per year

1970

| | Basin Area | Yield | Run-off | Altered Area | Run-off |
|---|---|---|---|---|---|
| 2" (5.08mm) | *12 sq mi (31.08 sq km) | 5.45" (13.84 mm) | 3488 afy (430.8 hmy) | 37 $mi^2$ (95.83 $km^2$) | 10,755 afy (1328.5 hmy) |
| 4" (10.16) | 10 (25.9) | 4.35 (11.05) | 2320 (286.6) | 10 (25.9) | 2320 (286.6) |
| 6" (15.24) | 17 (44.03) | 3.12 (7.92) | 2829 (349.5) | 17 (44.03) | 2829 (349.5) |
| 10" (25.4) | 46 (119.14) | 0 (0.0) | 0 (0) | 21 (54.39) | 0 (0) |
| Water | 15 (38.85) | 2.00 (5.08) | 1600 (197.6) | 15 (38.85) | 1600 (197.6) |
| | 100 (259) | | 10,237 (1264.5) | 100 (259) | 17,504 (2162.2) |

1971

| | Basin Area | Yield | Run-off | Altered Area | Run-off |
|---|---|---|---|---|---|
| 2" (5.08) | 12 (31.08) | 3.47 (8.81) | 2221 (274.3) | 37 (95.83) | 6847 (845.8) |
| 4" (10.16) | 10 (25.9) | 2.57 (6.53) | 1371 (169.4) | 10 (25.9) | 1371 (169.4) |
| 6" (15.24) | 17 (44.03) | 1.70 (4.32) | 1541 (190.4) | 17 (44.03) | 1541 (190.4) |
| 10" (25.4) | 46 (119.14) | .82 (2.09) | 2012 (248.5) | 21 (54.39) | 918 (113.4) |
| Water | 15 (38.85) | 0 | 0 | 15 (38.85) | 0 |
| | | | 7145 (882.6) | | 10677 (1318.9) |

*Bracketed figures are metric conversions.

1972

| | Basin Area | Yield | Run-Off | Altered Area | Run-off |
|---|---|---|---|---|---|
| 2" (5.08) | 12 (31.08) | 7.86 (19.96) | 5030 (621.3) | 37 (95.83) | 15,510 (1915.9) |
| 4" (10.16) | 10 (25.9) | 4.20 (10.67) | 2240 (276.7) | 10 (25.9) | 2240 (276.7) |
| 6" (15.24) | 17 (44.03) | 2.20 (5.59) | 1995 (246.4) | 17 (44.03) | 1995 (246.4) |
| 10" (25.4) | 46 (119.14) | 0 (0.0) | 0 (0) | 21 (54.39) | 0 (0) |
| Water | 15 (38.85) | 3.14 (7.97) | 2512 (310.3) | 15 (38.85) | 2512 (310.3) |
| | | | 11777 (1454.8) | | 22257 (2749.3) |

1973

| | Basin Area | Yield | Run-Off | Altered Area | Run-off |
|---|---|---|---|---|---|
| 2" (5.08) | 12 (31.08) | 5.86 (14.89) | 3750 (463.2) | 37 (95.83) | 11564 (1428.4) |
| 4" (10.16) | 10 (25.9) | 5.31 (13.49) | 2832 (349.8) | 10 (25.9) | 2832 349.8) |
| 6" (15.24) | 17 (44.03) | 3.31 (8.41) | 3001 (370.7) | 17 (44.03) | 3001 (370.7) |
| 10" (25.4) | 46 (119.14) | 0 (0.0) | 0 (0) | 21 (54.39) | 0 (0) |
| Water | 15 (38.85) | 5.33 (13.54) | 4264 (526.7) | 15 (38.85) | 4264 (526.7) |
| | | | 13847 (1710.5) | | 21661 (2675.7) |

(Figures in brackets are metric conversions)

1974

| | Basin Area | Yield | Run-off | Altered Area | Run-off |
|---|---|---|---|---|---|
| 2" (5.08) | 12 (31.08) | 5.13 (13.03) | 3283 (405.5) | 37 (95.83) | 10123 (1250.4) |
| 4" (10.16) | 10 (25.9) | 5.13 (13.03) | 2736 (337.9) | 10 (25.9) | 2736 (337.9) |
| 6" (15.24) | 17 (44.03) | 5.13 (13.03) | 4651 (574.5) | 17 (44.03) | 4651 (574.5) |
| 10" (25.4) | 46 (119.14) | 4.44 (11.28) | 10893 (1345.6) | 21 (54.39) | 4973 (614.3) |
| Water | 15 (38.85) | 0 | 0 | 15 (38.83) | 0 0 |
| | | | 21563 (2663.6) | | 22483 (2777.2) |

1975

| | Basin Area | Yield | Run-off | Altered Area | Run-off |
|---|---|---|---|---|---|
| 2" (5.08) | 12 (31.08) | 2.37 (6.02) | 1517 (187.4) | 37 (95.83) | 4677 (577.7) |
| 4" (10.16) | 10 (25.9) | 0 | 0 | 10 (25.9) | 0 |
| 6" (15.24) | 17 (44.03) | 0 | 0 | 17 (44.03) | 0 |
| 10" (25.4) | 46 (119.14) | 0 | 0 | 21 (54.39) | 0 |
| | | | 3085 (381.1) | | 6245 (771.4) |

(Figures in brackets are metric conversions)